SOUTH CHINA NORMAL UNIVERSITY

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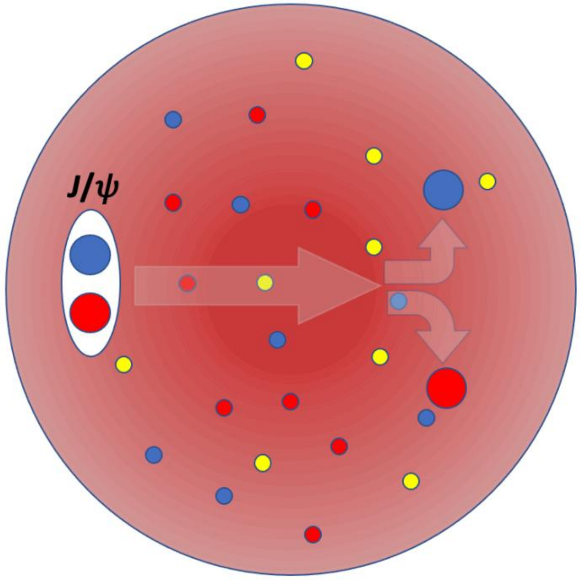
J/ψ R_{AA} in Au+Au collisions at 14.6, 17.3, 19.6 and 27 GeV

Wei Zhang
South China Normal University

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



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

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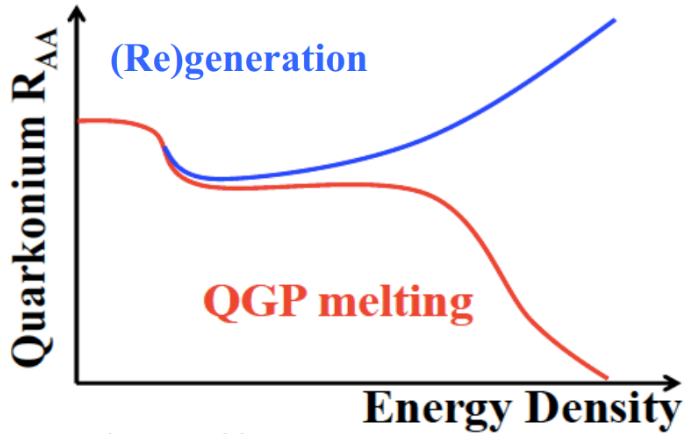
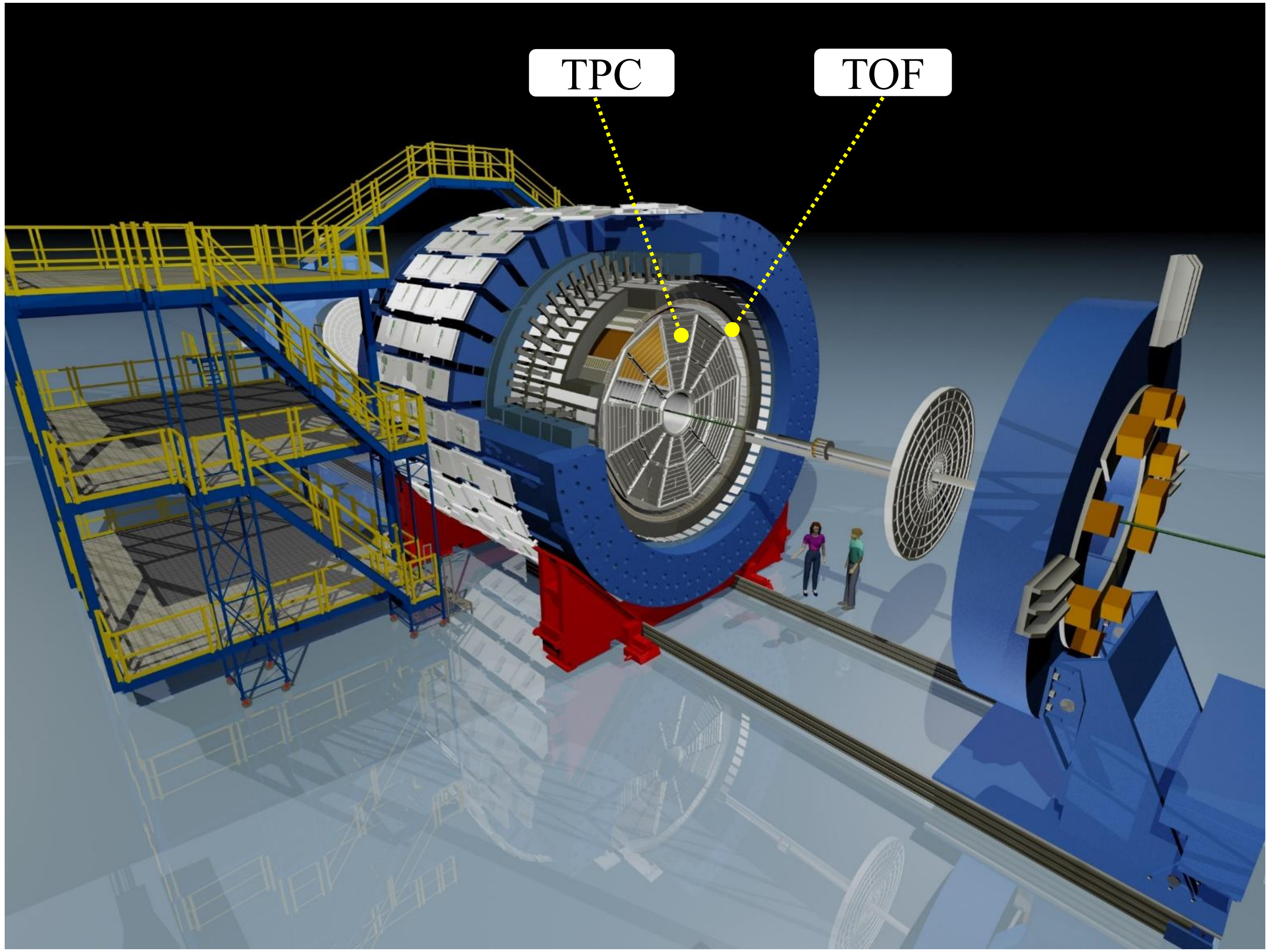


$$R_{AA} = \frac{\sigma_{\text{inel}}}{\langle N_{coll} \rangle} \frac{d^2 N_{AA}/dydp_T}{d^2 \sigma_{pp}/dydp_T}$$

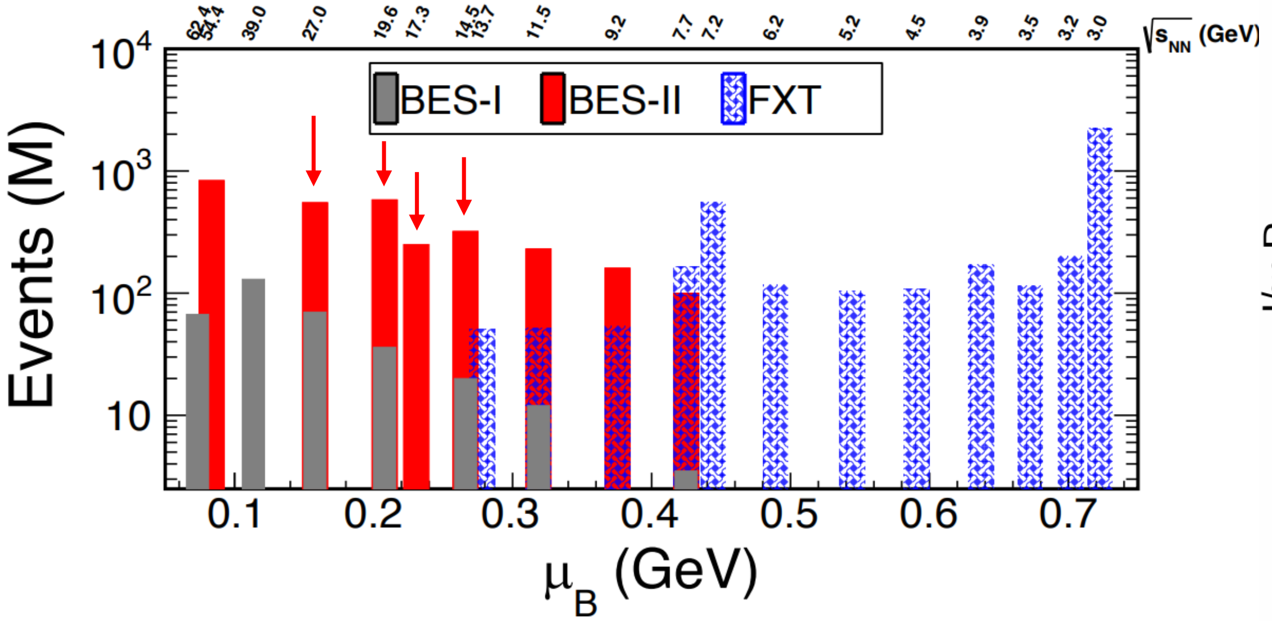
STAR Detector

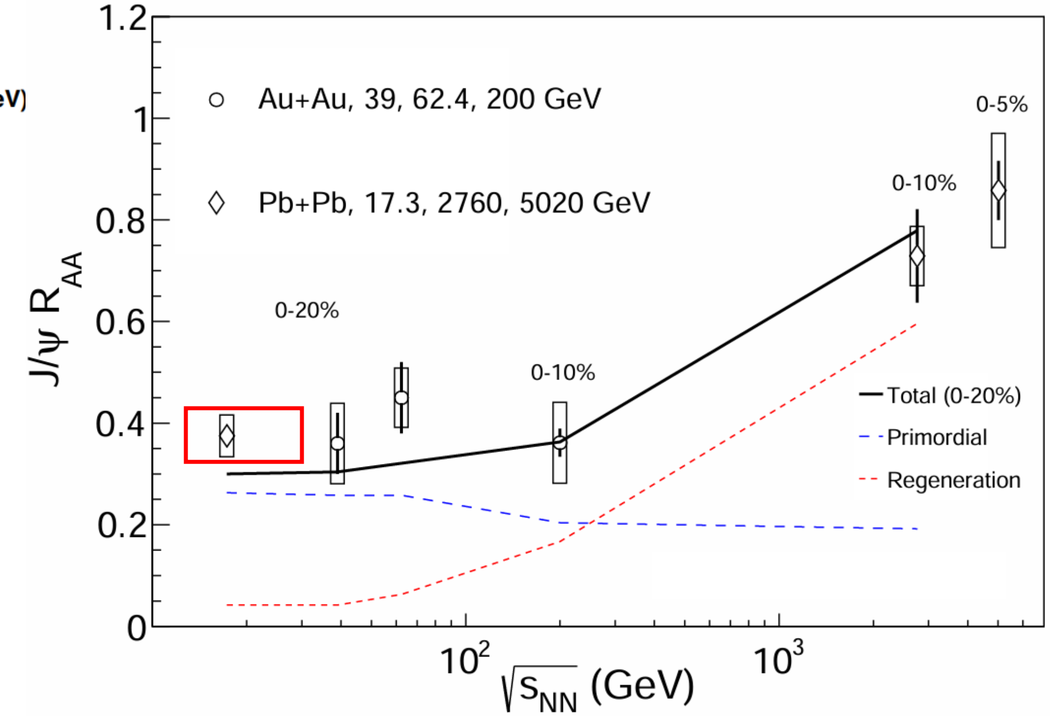


- **Time Projection Chamber**
  - Tracking
  - Momentum and energy loss
  - Acceptance: $|\eta| < 1.5$; $0 \leq \varphi < 2\pi$

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

Au+Au Collisions at STAR





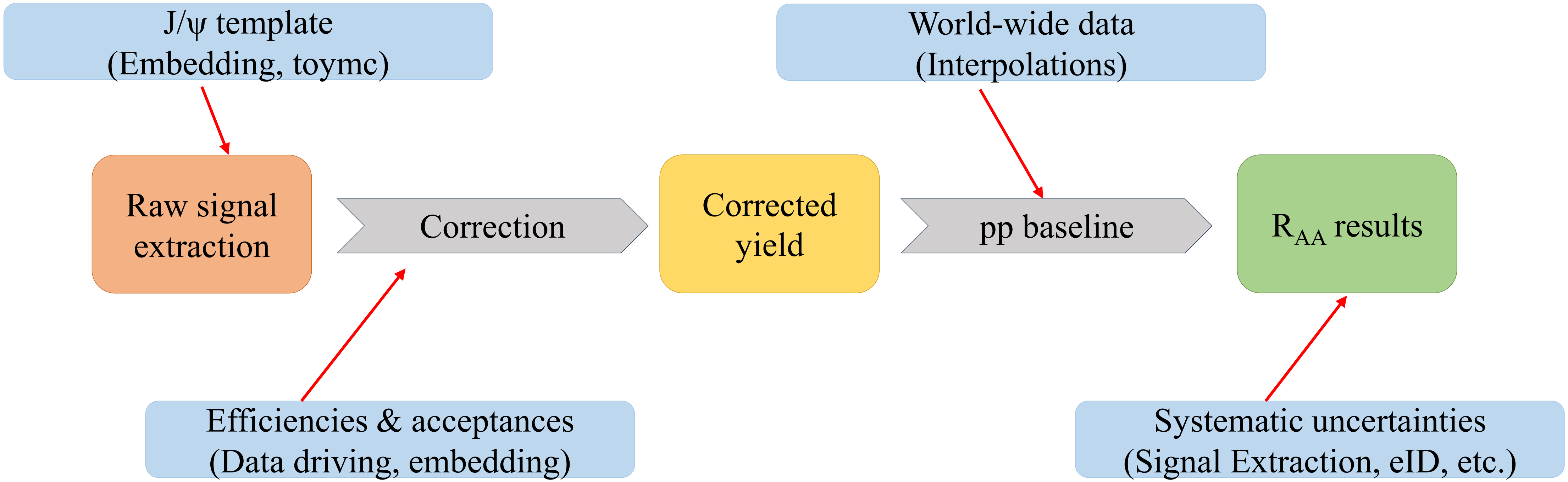
STAR Collaboration Phys. Lett. B 771 (2017) 13–20

- 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

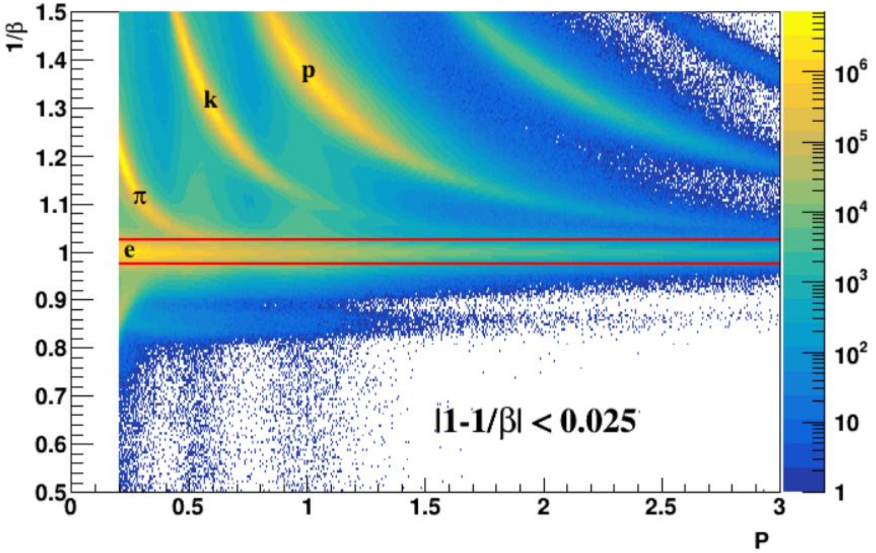
Analysis Procedure

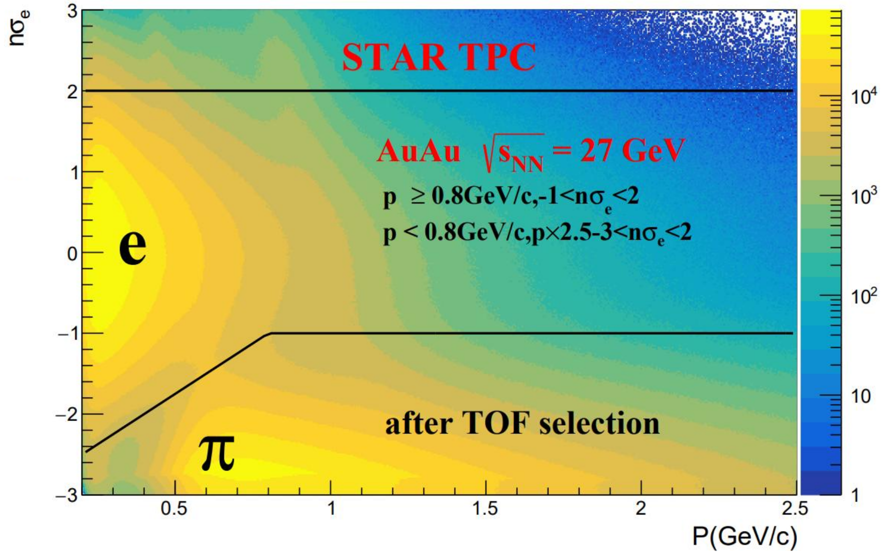
Observable: $$R_{AA} = \frac{\sigma_{\text{inel}}}{\langle N_{coll} \rangle} \frac{d^2 N_{AA}/dydp_T}{d^2 \sigma_{pp}/dydp_T} \begin{cases} < 1 & \text{suppression} \\ = 1 & \text{no net medium effects} \\ > 1 & \text{enhancement} \end{cases}$$



Electron Identification

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

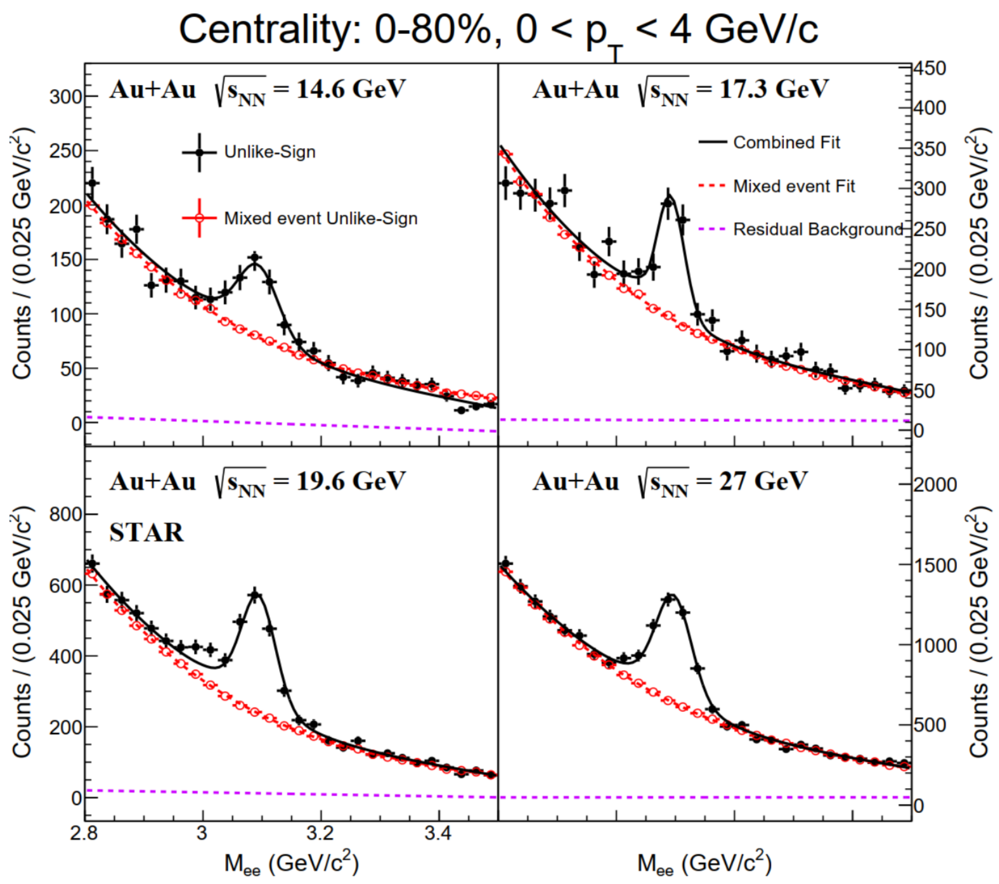




$$n\sigma_e = \frac{1}{R} log \frac{(dE/dx)_{measured}}{(dE/dx)_{electron}}$$

Raw J/ψ Signal

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



- 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

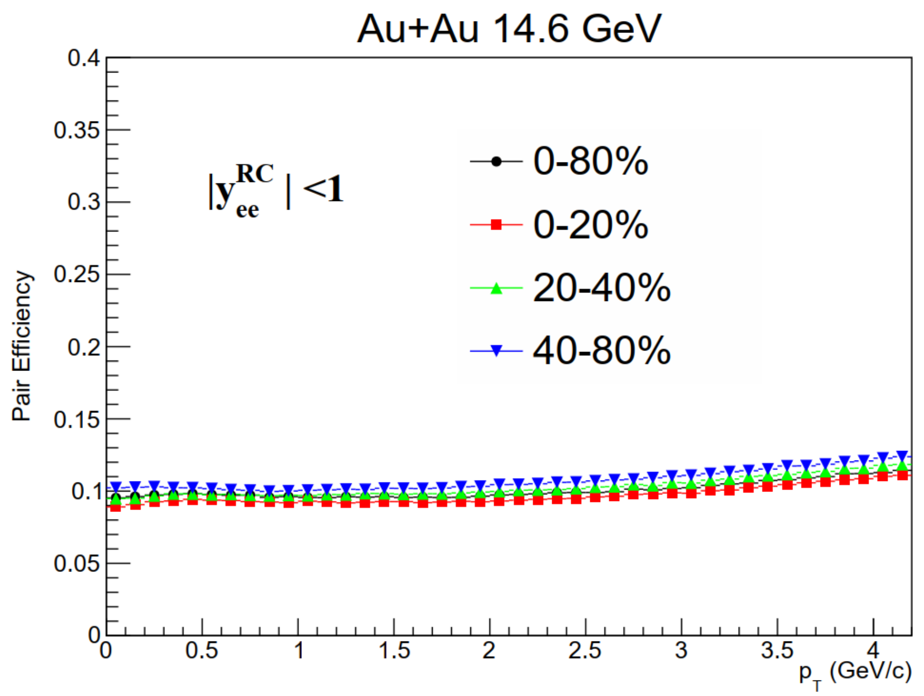
Efficiency and Acceptance Corrections

$$R_{AA} = \frac{\sigma_{\text{inel}}}{\langle N_{coll} \rangle} \frac{\boxed{d^2 N_{AA}}/dydp_T}{d^2\sigma_{pp}/dydp_T} \qquad N_{AA} = \frac{N_{J/\psi \to e+e-}}{A \times \varepsilon \times Nevent}$$

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

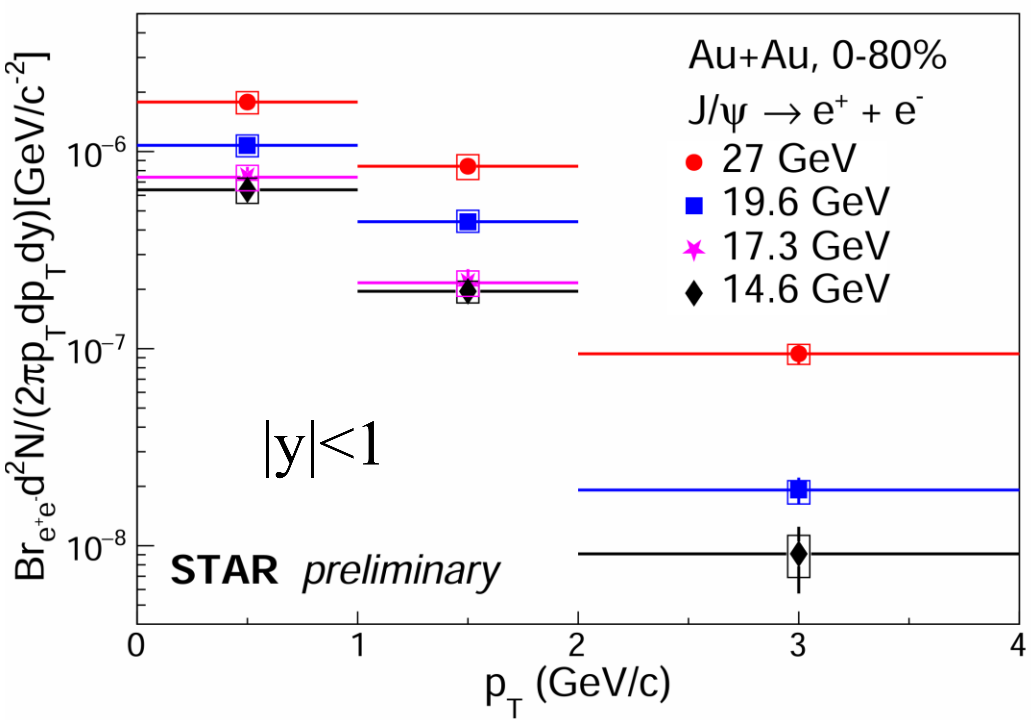
  $\varepsilon_{\text{electron}} = \varepsilon_{\text{positron}} = \varepsilon_{\text{TPC}} \times \varepsilon_{\text{eID}} \times \varepsilon_{\text{TOF}}$

- The pair efficiency is obtained by folding the single-electron efficiencies and applying the acceptance cut using a toy MC: $A \times \varepsilon = A \times \varepsilon_{\text{electron}} \times \varepsilon_{\text{positron}}$



Inclusive J/ψ Invariant Yields

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



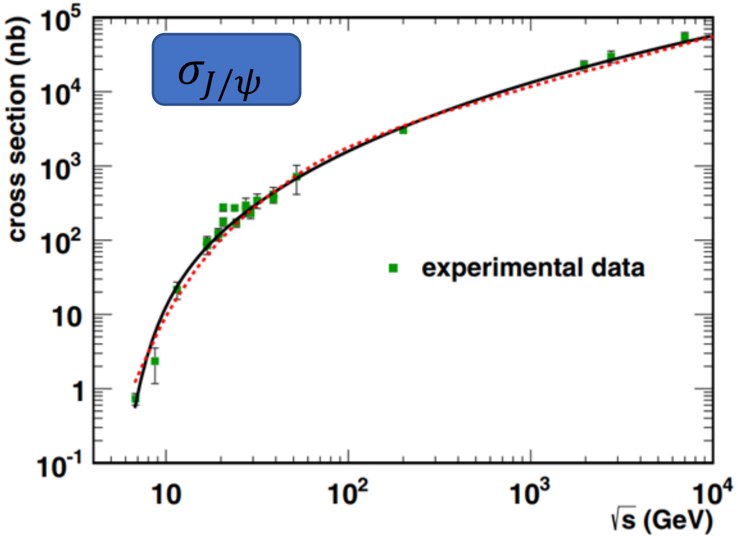
Inclusive J/ψ invariant yields as a function of p_T at mid-rapidity ($|y| < 1$) in Au+Au collisions at $\sqrt{s_{NN}}$ = 14.6, 17.3, 19.6, 27 GeV.

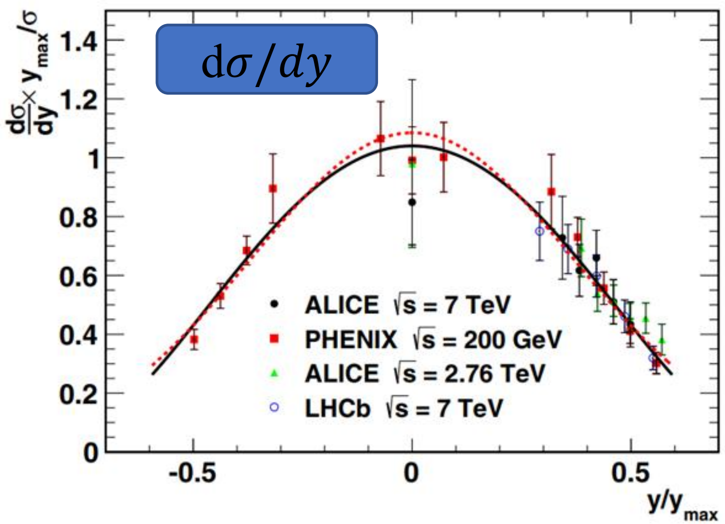
p+p Baseline

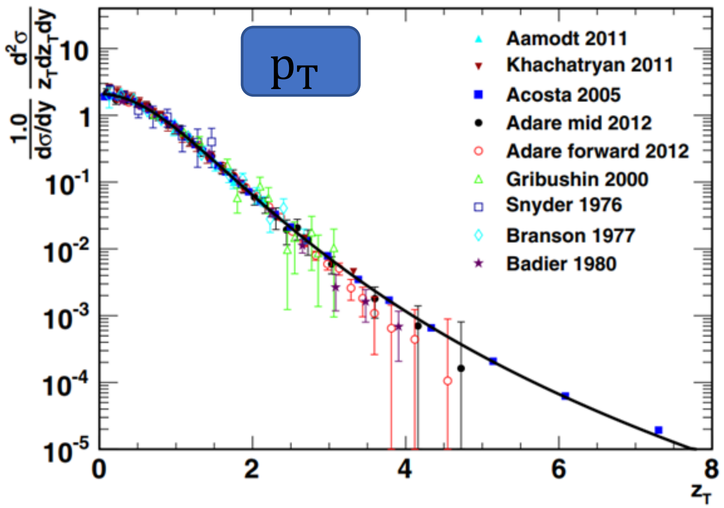
$$R_{AA} = \frac{\sigma_{\text{inel}}}{\langle N_{coll} \rangle} \frac{d^2 N_{AA}/dydp_T}{\boxed{d^2 \sigma_{pp}/dydp_T}}$$

- **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

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

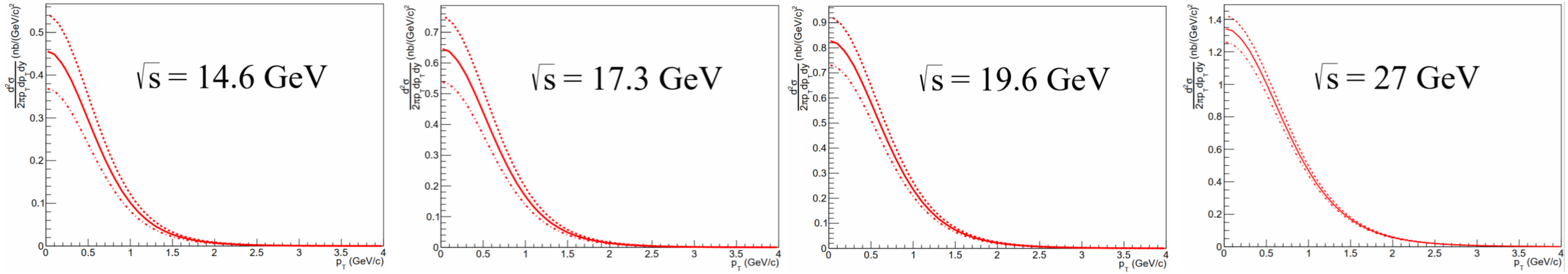
where $y_{max} = ln(\frac{\sqrt{s}}{m_{J/\psi}})$

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

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

p+p Baseline

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



- 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:

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

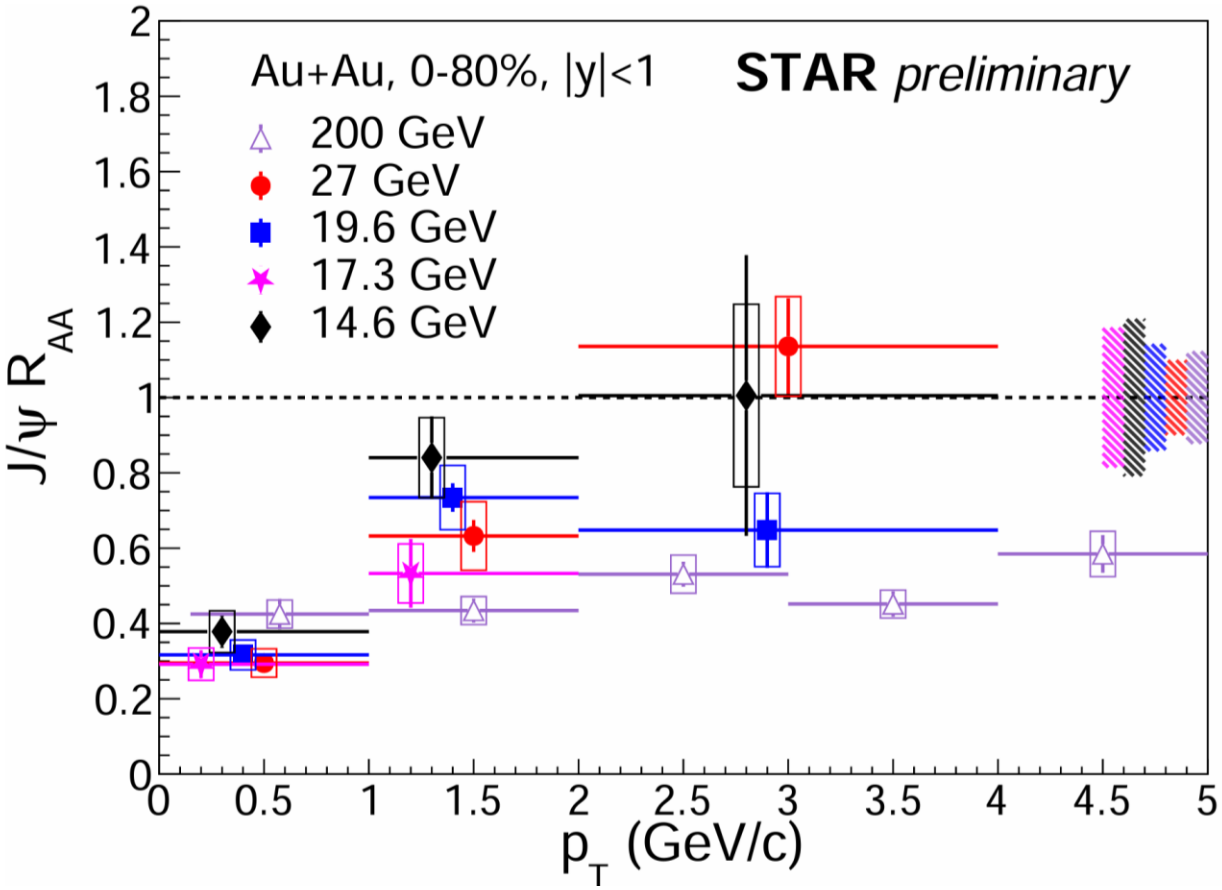
Systematic Uncertainties

Source：

- **Track quality cuts**
  - nHitsFit
  - nHitsDedx
  - 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

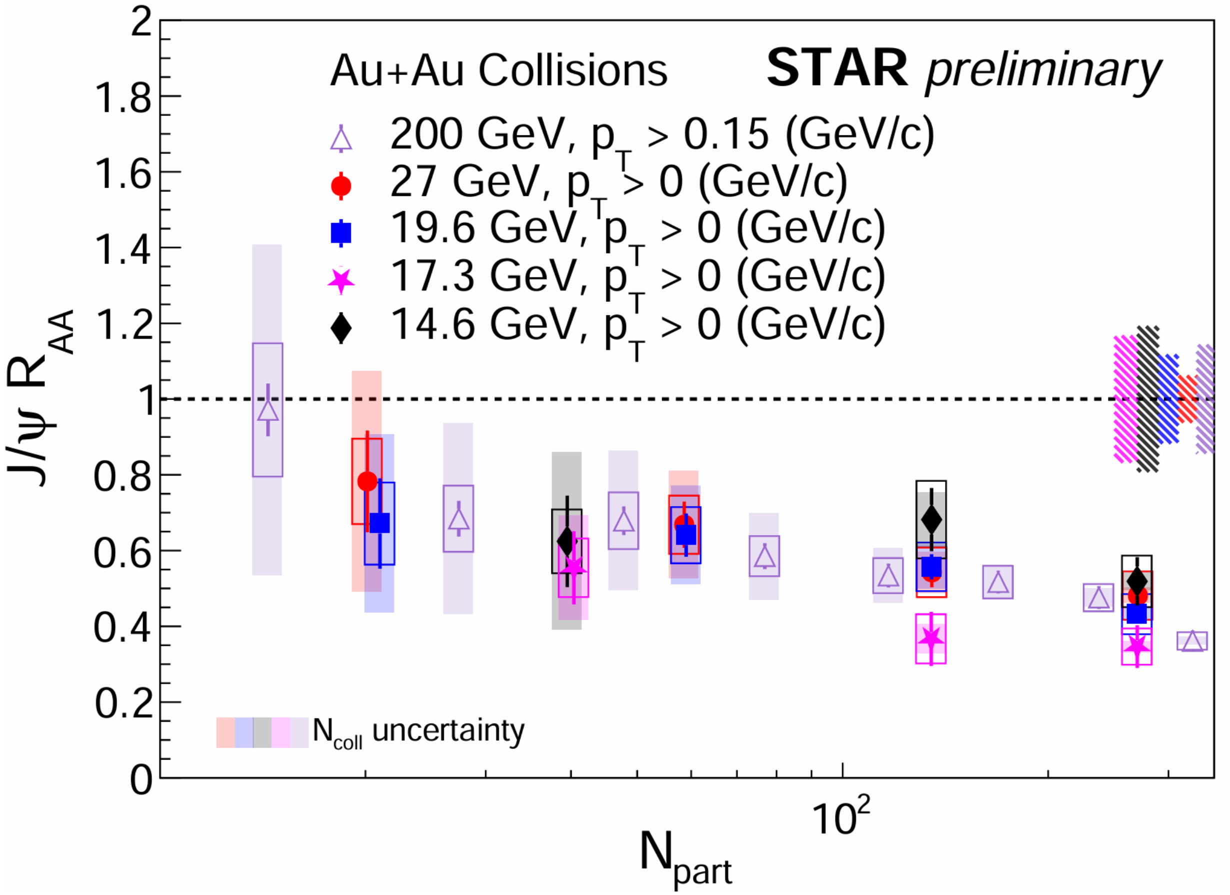
Au+Au	14.6 GeV	17.3 GeV	19.6 GeV	27 GeV
signal extraction	4.5 – 6.0%	4.1 – 8.8%	3.2 – 7.5%	1.8 – 3.8%
TPC tracking	1.7 – 6.8%	4.9 – 8.2%	4.4 – 7.8%	10.2 – 10.8%
TOF matching	0.15 – 2.9%	0.3 – 1%	0.7 – 2.1%	0.06 – 1.9%
$1/\beta$ cut	1.3 – 2.2%	2.3 – 2.6%	0.8 – 2.0%	2.1 – 3.7%
$n\sigma_e$ cut	1.7 – 6.7%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



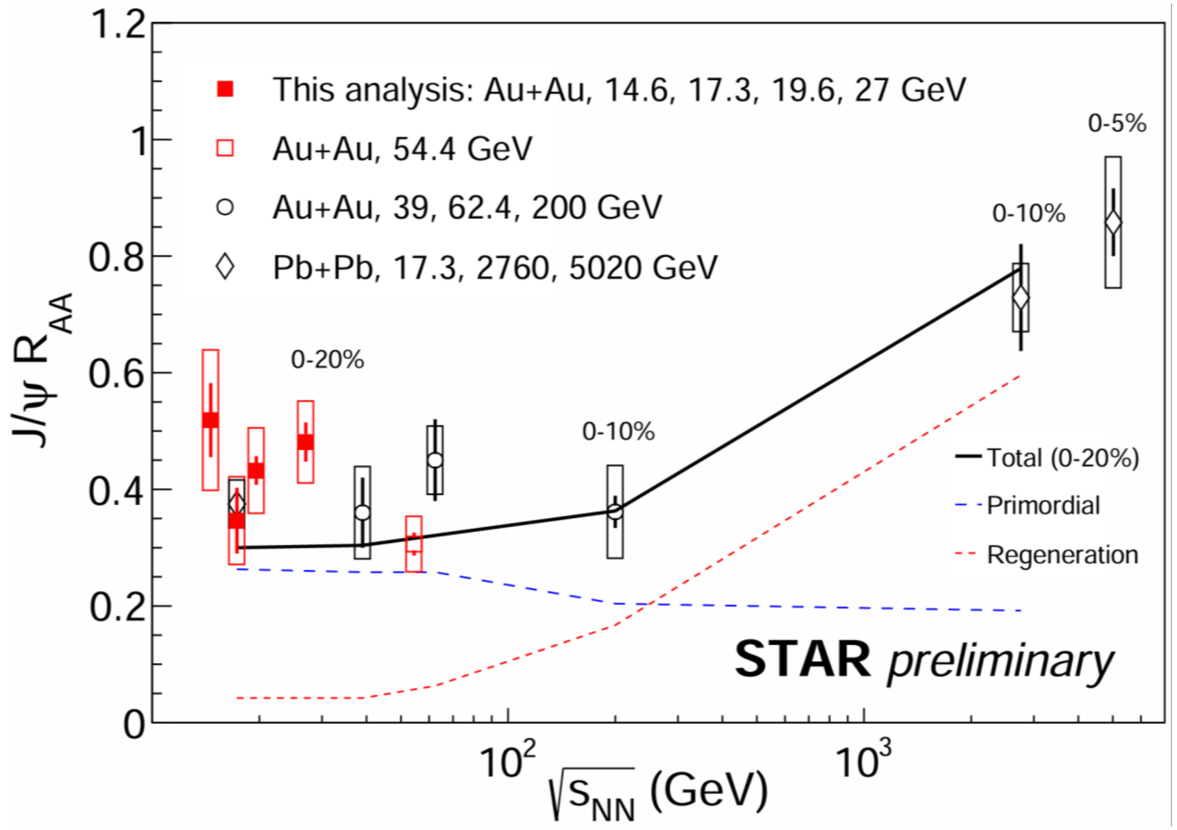
- ➢ Low p_T suppression, R_{AA} increases with p_T for $\sqrt{s_{NN}}$ = 14.6, 17.3, 19.6 and 27 GeV
- ➢ No significance p_T dependence at 200 GeV

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, 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

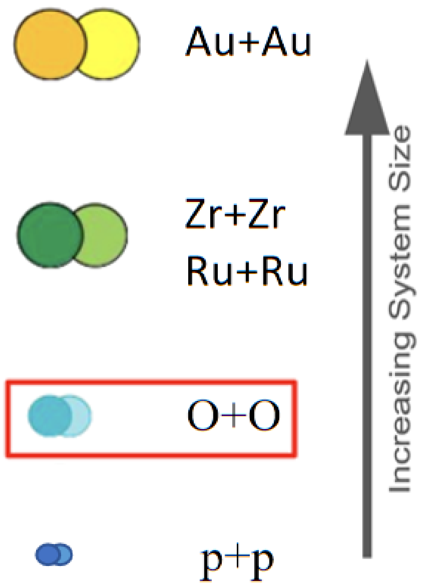
- ➢ Significant suppression of charmonium in central heavy-ion collisions
- ➢ J/ψ R_{AA} increases with p_T, hint of decreasing with centrality
- ➢ No significant collision energy dependence of J/ψ R_{AA} at RHIC

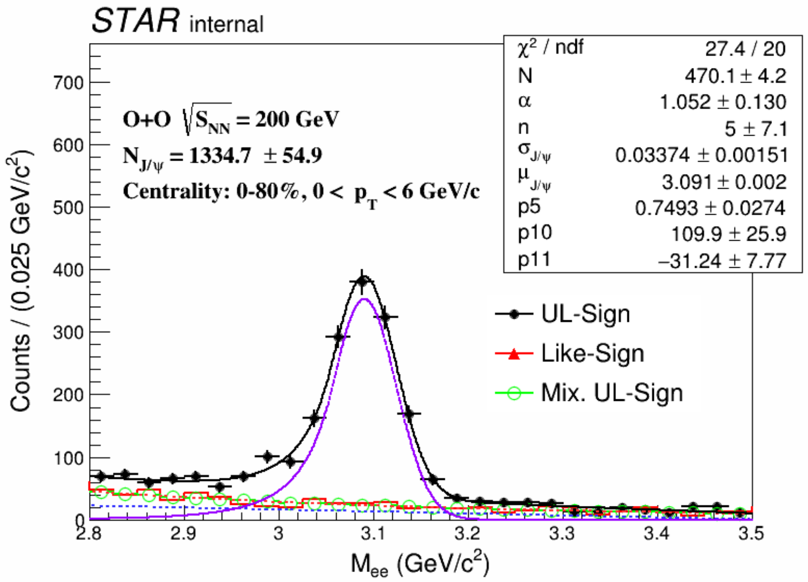
→ Interplay of dissociation, regeneration and cold nuclear matter effects

→ 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





Thank you

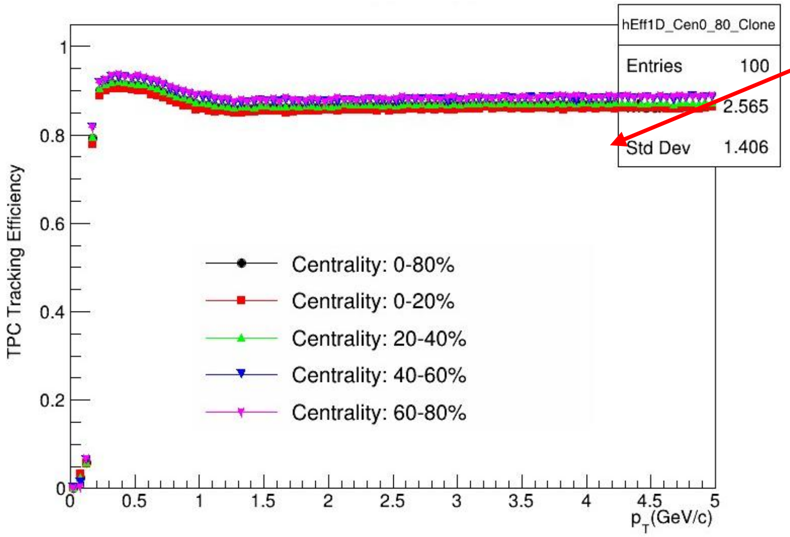
Back up

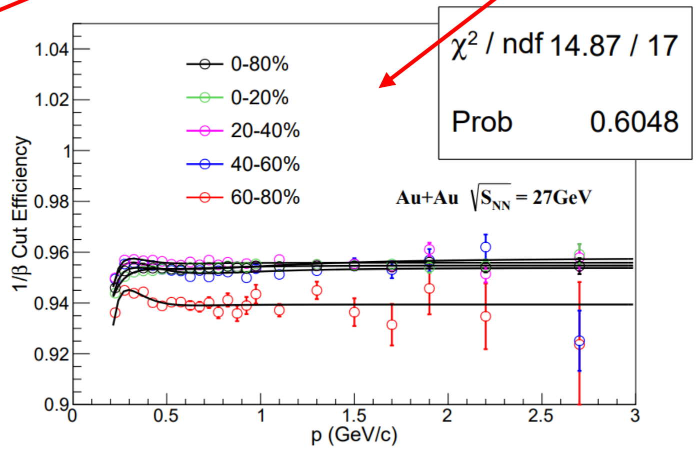
Efficiency and Acceptance Corrections

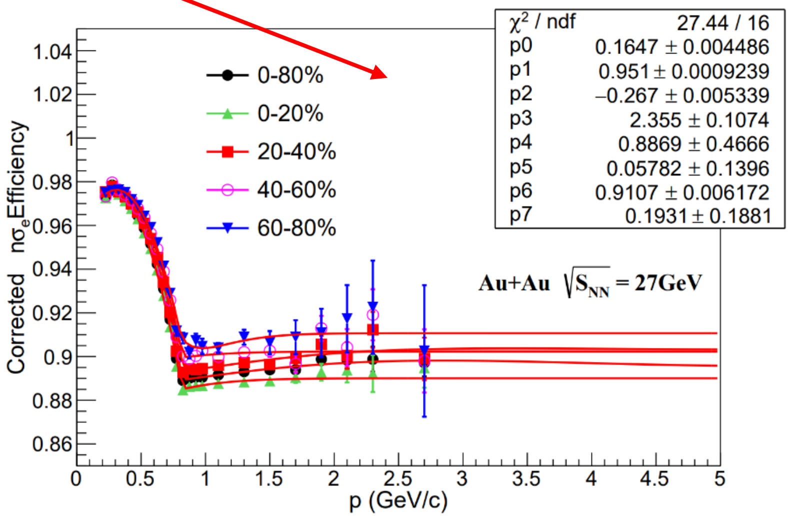
$$R_{AA} = \frac{\sigma_{\mathrm{inel}}}{\langle N_{coll} \rangle} \frac{\boxed{d^2 N_{AA}}/dydp_T}{d^2\sigma_{pp}/dydp_T}$$

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

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



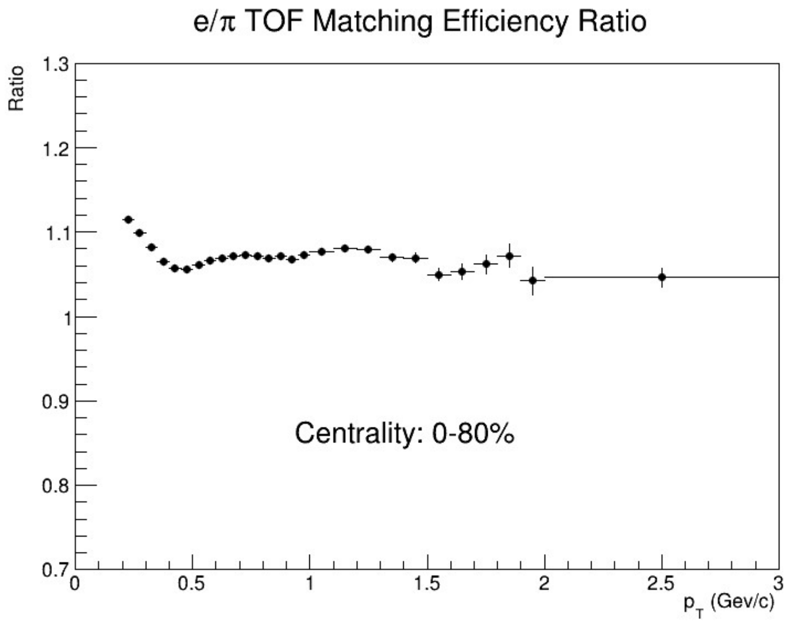


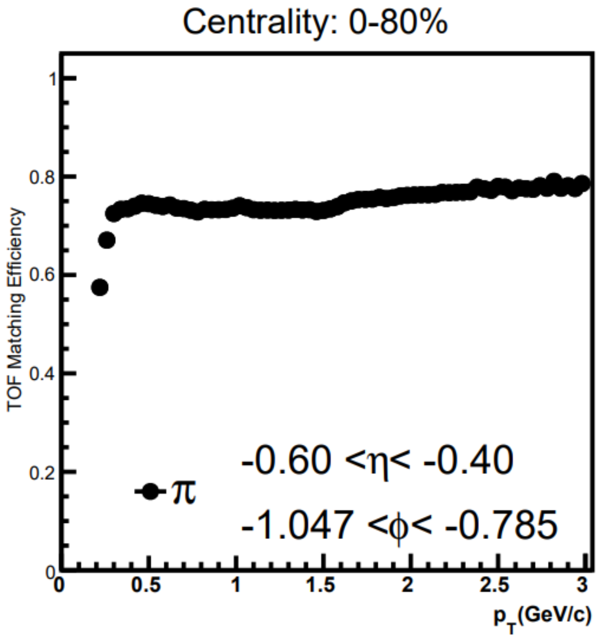


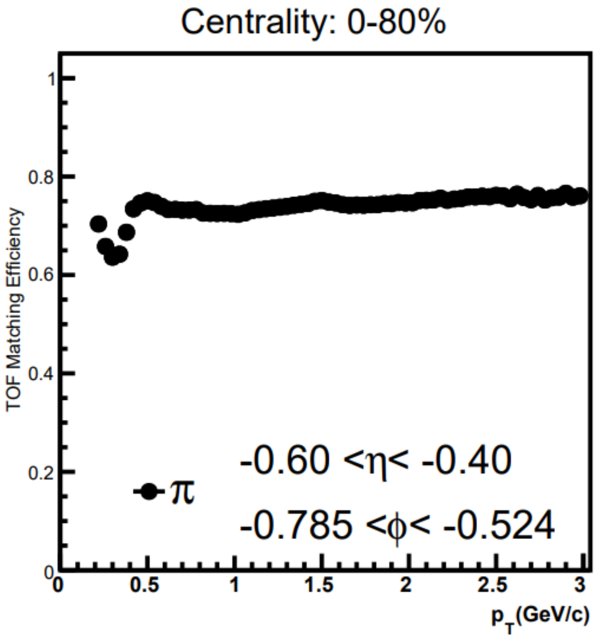
Efficiency and Acceptance Corrections

- TOF Matching efficiency has pt η Φ dependence

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





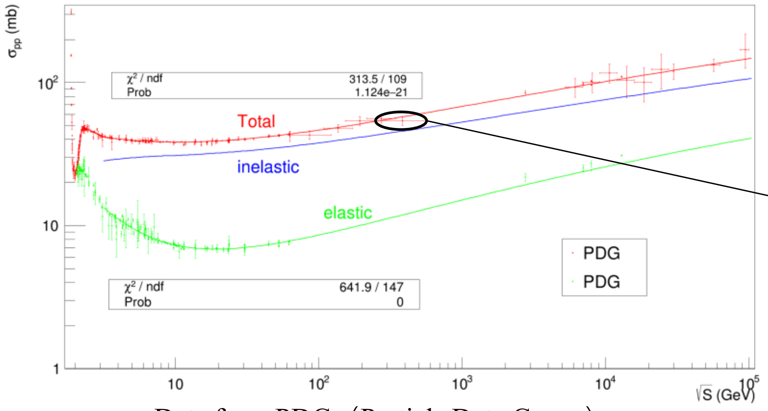


$$\frac{\text{Electron TOF Matching Efficiency(3D)}}{\text{Pion TOF Matching Efficiency(3D)}} = \frac{\text{Electron TOF matching efficiency (1D)}}{\text{Pion TOF matching efficiency (1D)}}$$

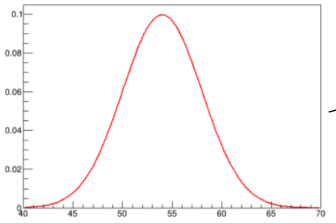
pp Inelastic Cross Section

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

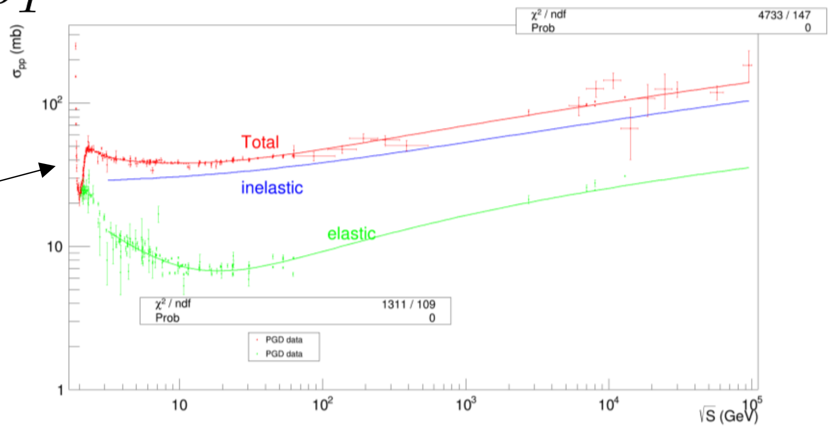
$$\sigma_{\mathrm{inelastic}} = \sigma_{\mathrm{total}} - \sigma_{\mathrm{elastic}}$$

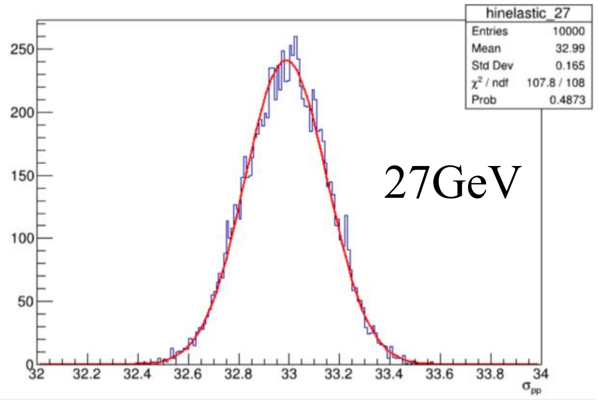


Data from PDG（Particle Data Group）：
https://pdg.lbl.gov/2022/hadronic-xsections/



Smearing each point



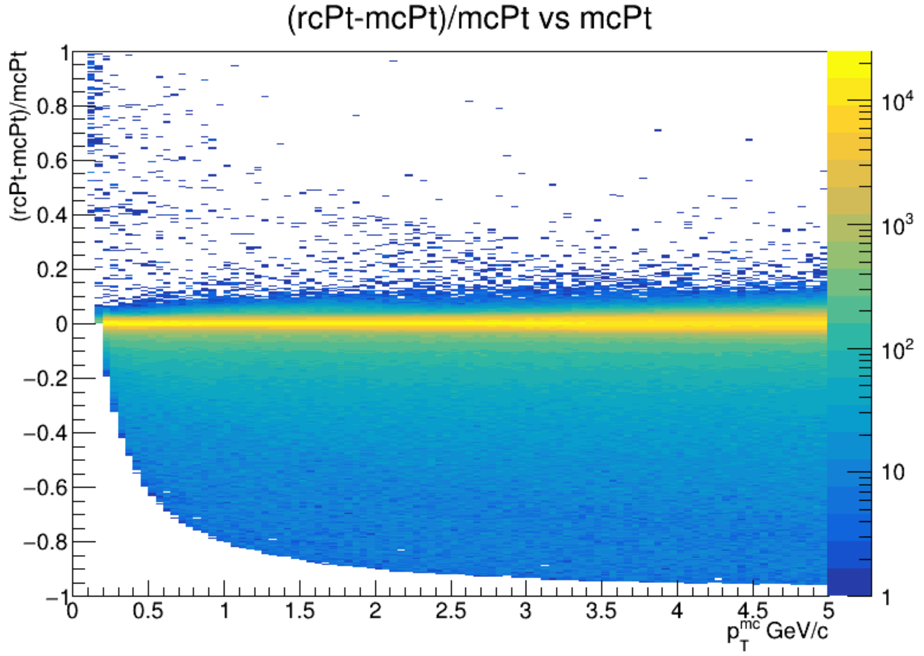


$\sqrt{S_{NN}}$ (GeV)	$\sigma_{\mathrm{inelastic}}$ (mb)	Error(mb)
200	43.40	0.77
27	32.99	0.16
19.6	32.08	0.14
17.3	31.78	0.13
14.6	31.42	0.13
11.5	30.99	0.12
9.2	30.65	0.13

Additional Momentum Smearing (27GeV example)

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

→ additional momentum smearing factor



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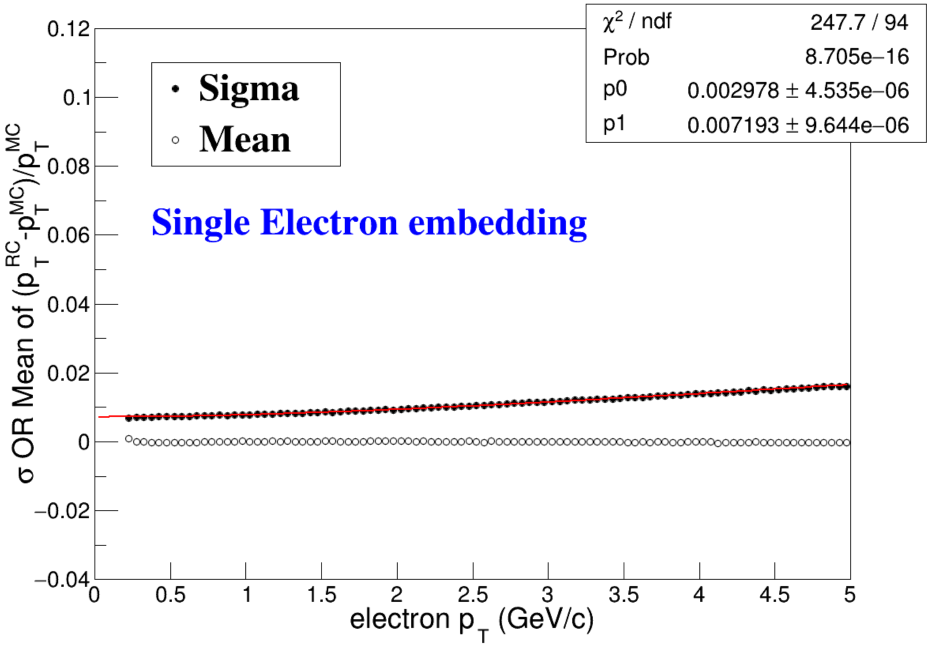
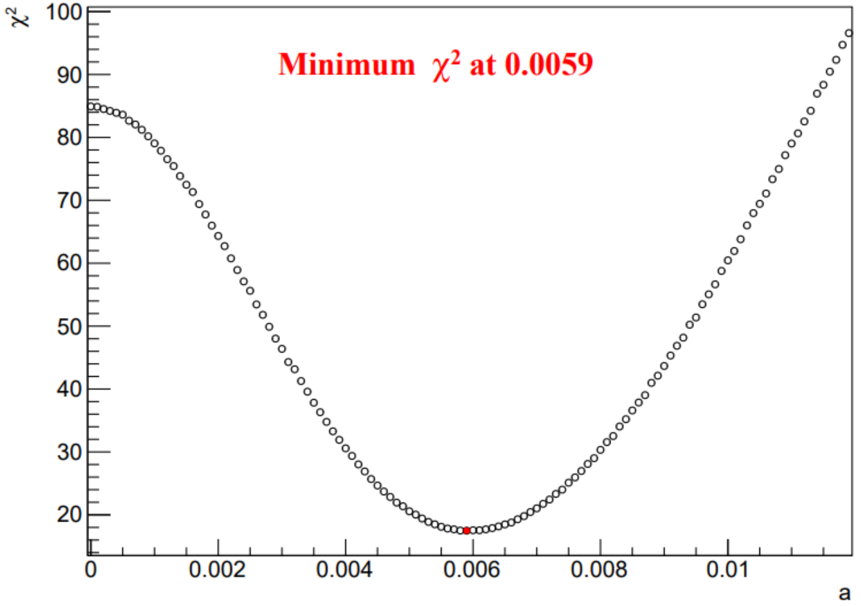
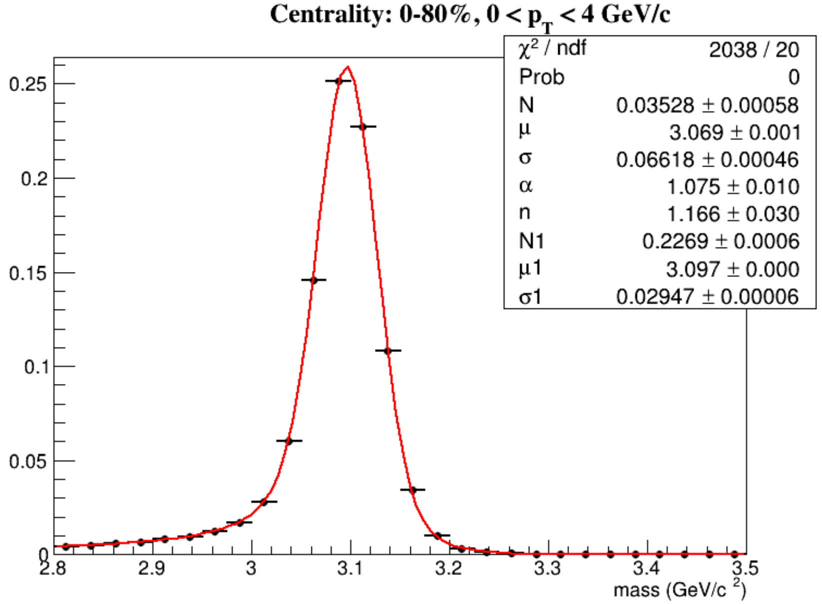


$$\sigma^{\ embed} = \sqrt{a^2 P_T{}^2 + b^2}$$

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

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