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University of Chinese Academy of Sciences

Cold Nuclear Matter Effects on Inclusive J/ψ and Υ Production in $p + \text{Au}$ Collisions at $\sqrt{s_{\text{NN}}} = 200 \text{ GeV}$ with STAR Experiment



Ziyue Zhang

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Spicy Gluons 2026, Wuhan

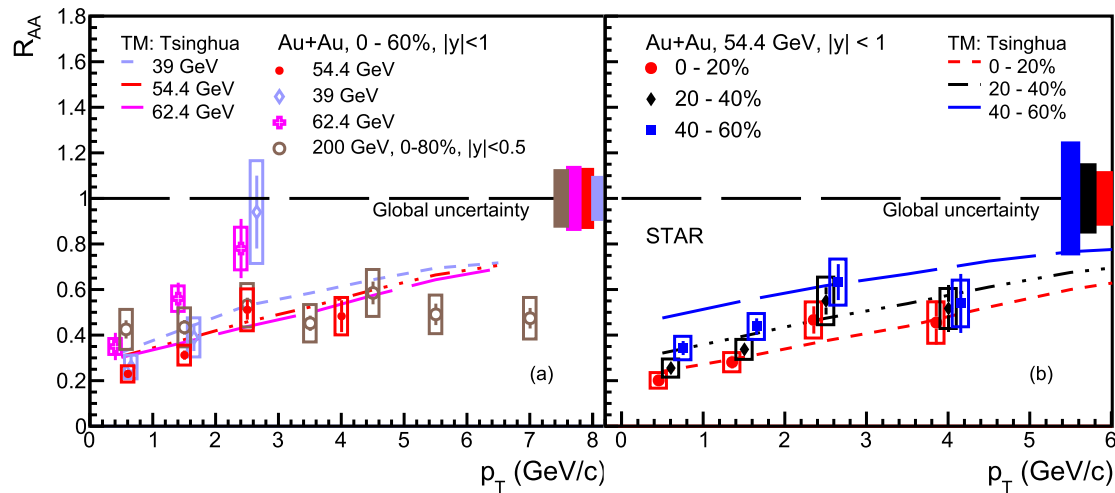
October 19, 2026

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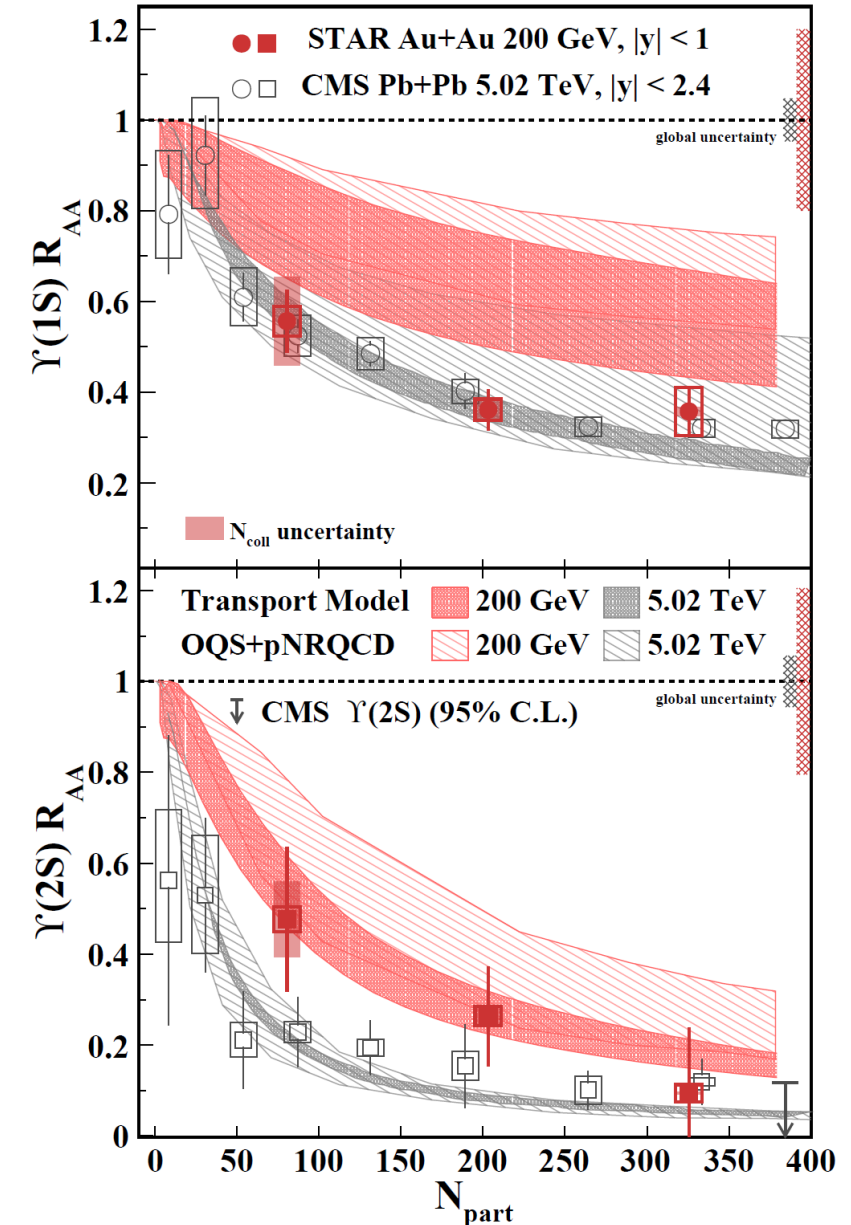
Physics Motivation

Quarkonia Suppression in Heavy-ion Collisions

- Significant suppression observed in $A - A$ collisions
- Disentangling hot-medium effects requires quantification of cold nuclear matter (CNM) effects



Phys. Lett. B 877, 140405 (2026)



Phys. Rev. Lett. 130, 112301 (2023)

R_{pA} as Baseline for Interpreting R_{AA}

- Definition of the nuclear modification factor:

$$R_{ab} = \frac{1}{\langle T_{ab} \rangle} \times \frac{\left(\frac{d^2 N}{2\pi p_T dp_T dy} \right)_{ab}}{\left(\frac{d^2 \sigma}{2\pi p_T dp_T dy} \right)_{pp}}$$

■ $\langle T_{ab} \rangle = \frac{\langle N_{\text{coll}} \rangle}{\sigma_{\text{NN}}^{\text{inel.}}}$: nuclear thickness function calculated by Glauber model

◆ $\langle N_{\text{coll}} \rangle$: average number of binary nucleon-nucleon collisions in minimum bias $a + b$ collisions

◆ $\sigma_{\text{NN}}^{\text{inel.}}$: inelastic nucleon-nucleon cross section at the given $\sqrt{s_{\text{NN}}}$

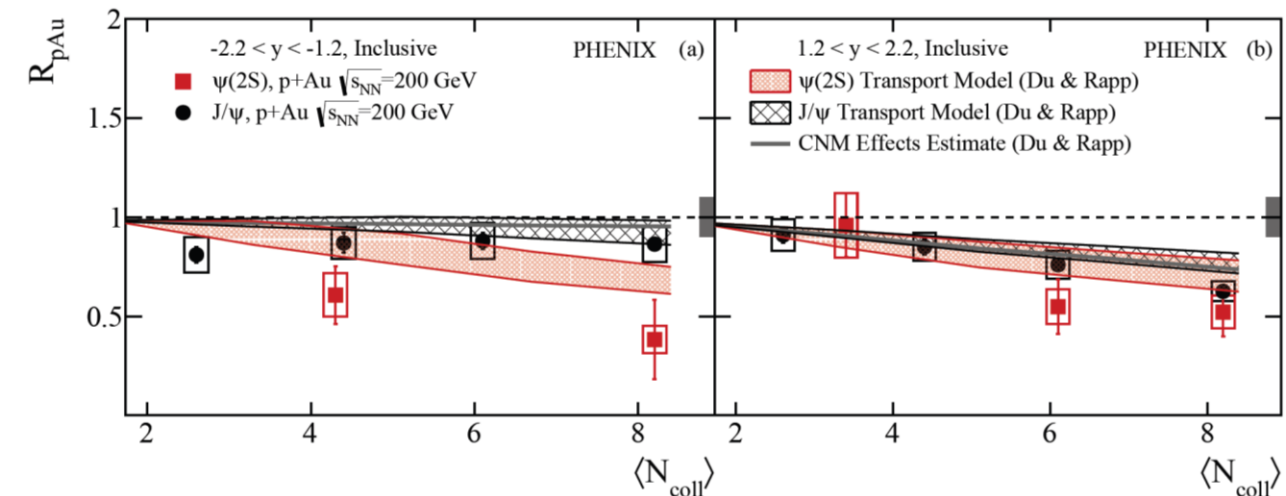
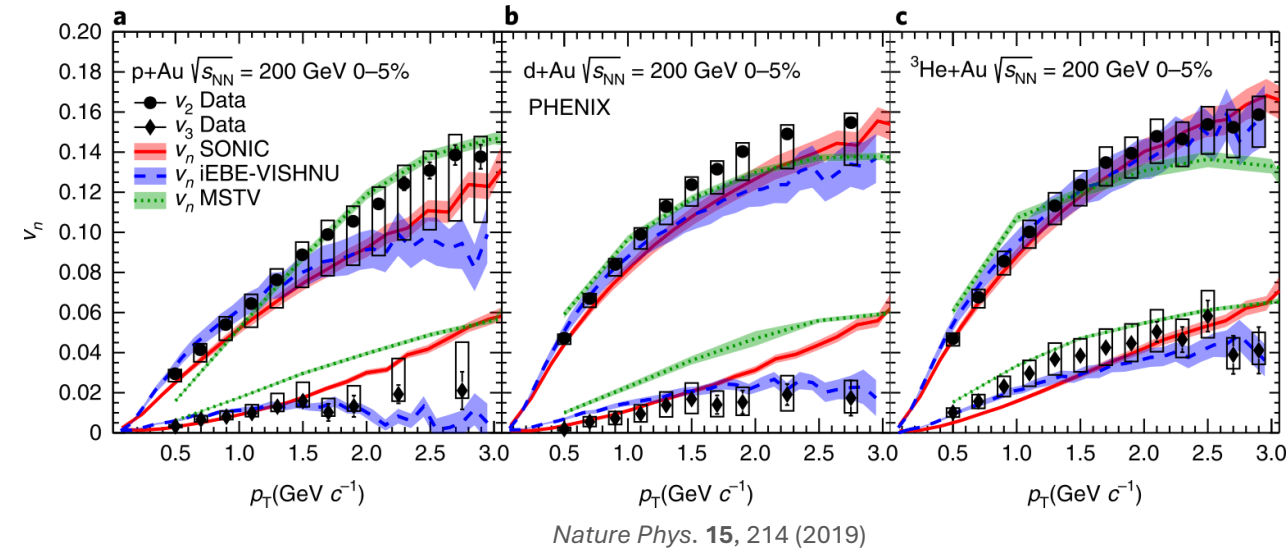
■ $\left(\frac{d^2 \sigma}{2\pi dp_T dy} \right)_{pp} = \left(\frac{d^2 N}{2\pi dp_T dy} \right)_{pp} \cdot \sigma_{pp}^{\text{NSD.}}$ Non-single-diffractive cross section of $p + p$ at $\sqrt{s_{\text{NN}}} = 200$ GeV, experimentally measured

- $p + A$ collisions were traditionally used to constrain CNM effects – assume no QGP formation

■ While recent observations of collective behavior in small systems raise questions on the such an assumption

Charmonia Collectivity and Suppression in Small Systems

- Collective anisotropies are more compatible to hydrodynamic evolution model
 - Hint of QGP droplets formation?
- Stronger $\psi(2S)$ suppression compared to J/ψ at backward region
 - Suggest final-state interactions
- Interpretation of R_{pA} involves both initial- and final-state effects



Cold Nuclear Matter Effects

- Initial-state effects

- Nuclear Parton Distribution Function (nPDF) effects

- Color-glass condensate

- Partonic propagation

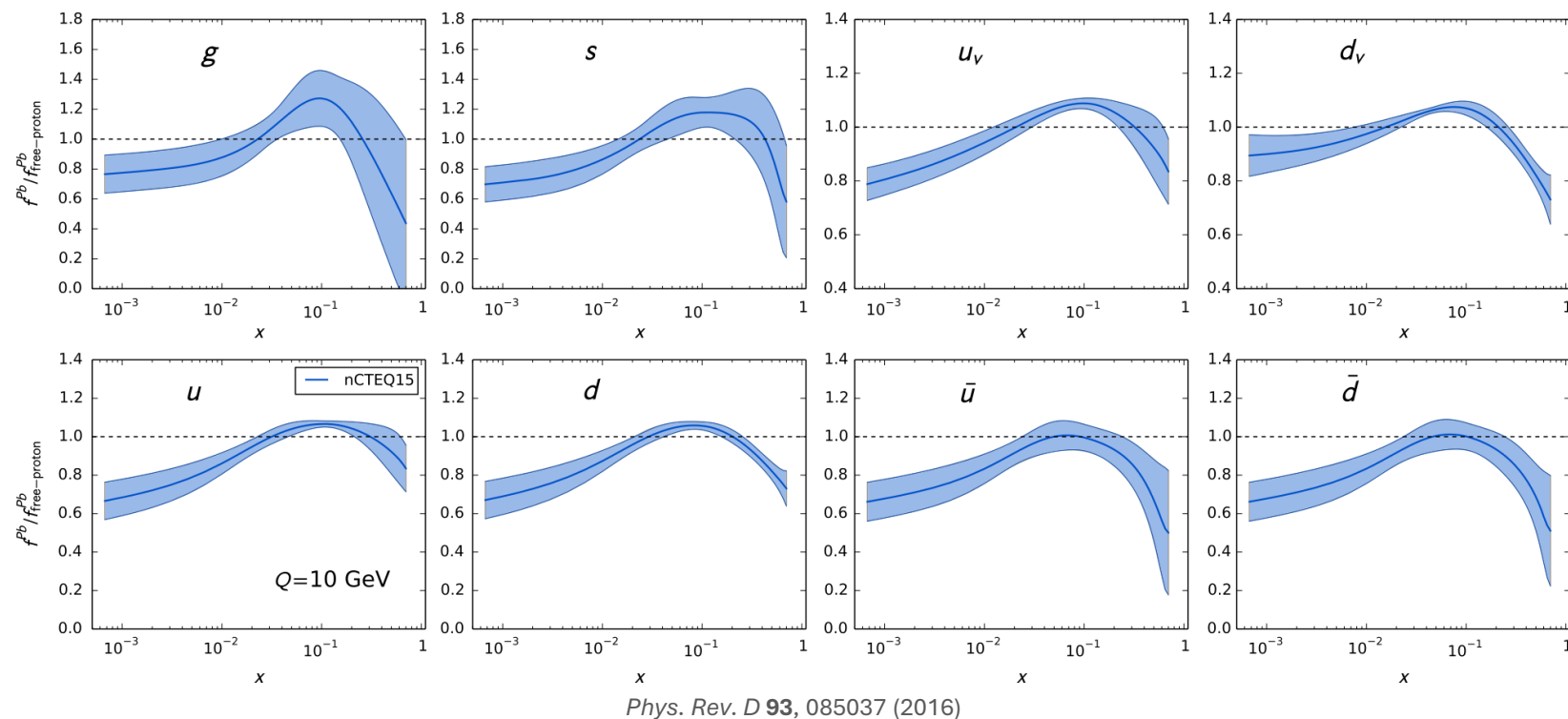
- Parton energy loss

- p_T broadening

- Final-state interactions

- Nuclear absorption

- Comover effects



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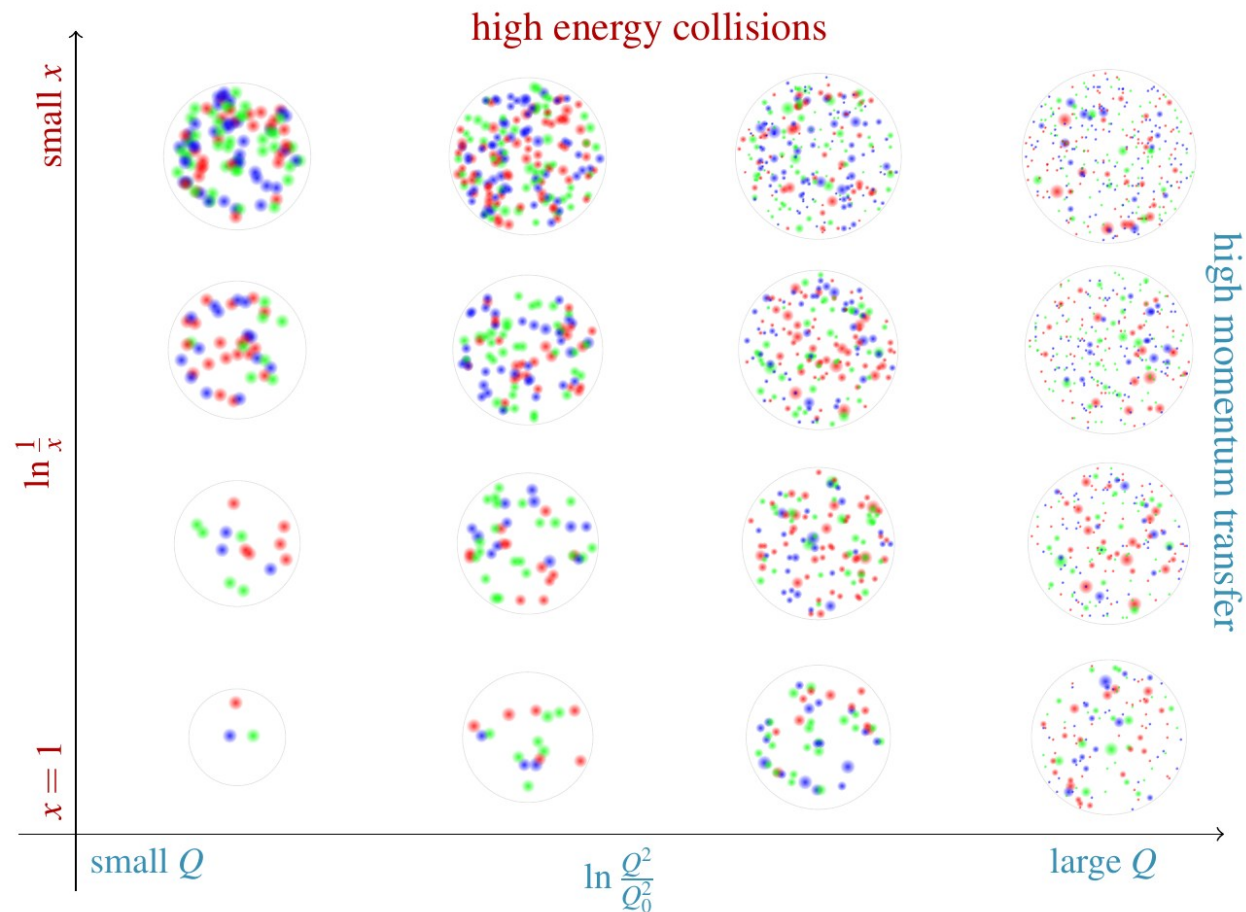
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Cold Nuclear Matter Effects

● Initial-state effects

- ## ■ Nuclear Parton Distribution Func (nPDF) effects

- ## ■ Color-glass condensate

● Partonic propagation

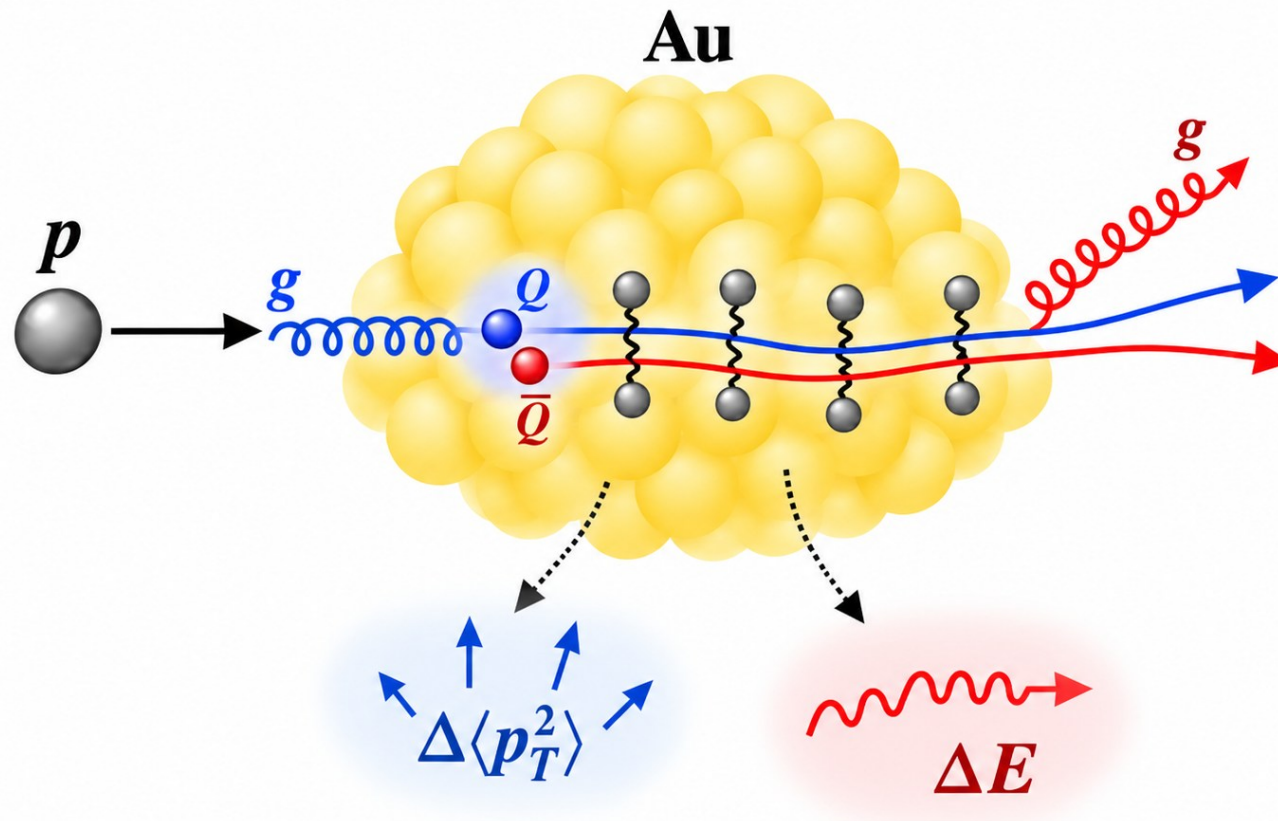
- ## ■ Parton energy loss

- p_T broadening

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- ## ■ Nuclear absorption

- ## ■ Comover effects



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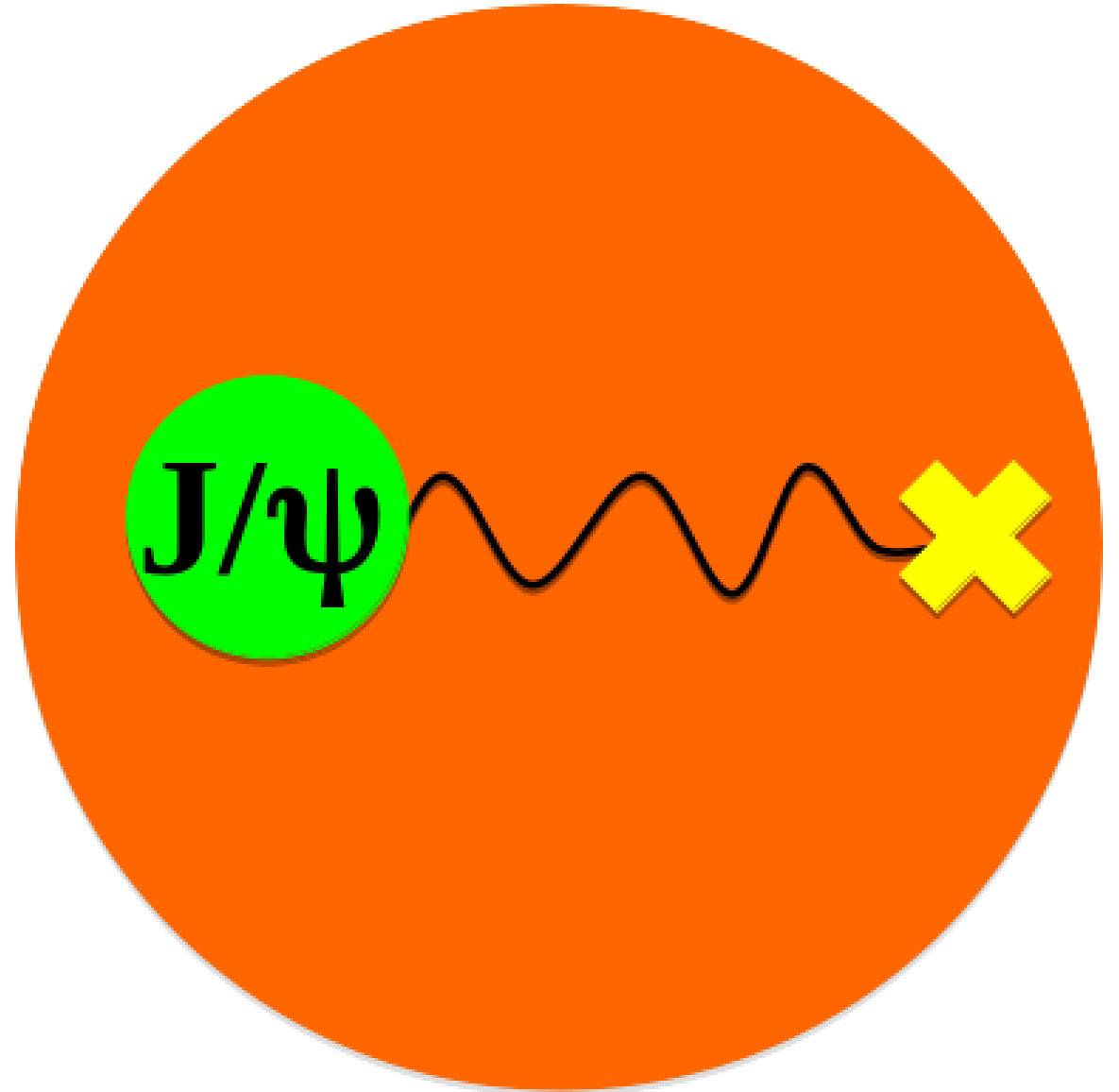
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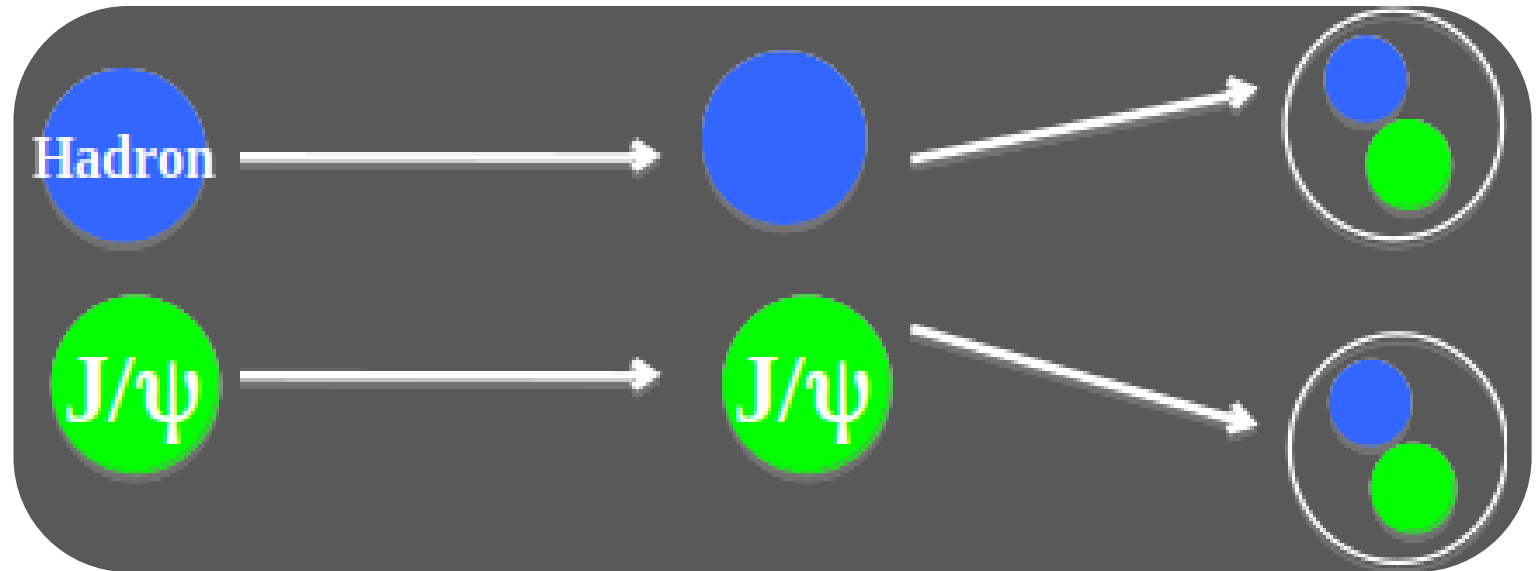
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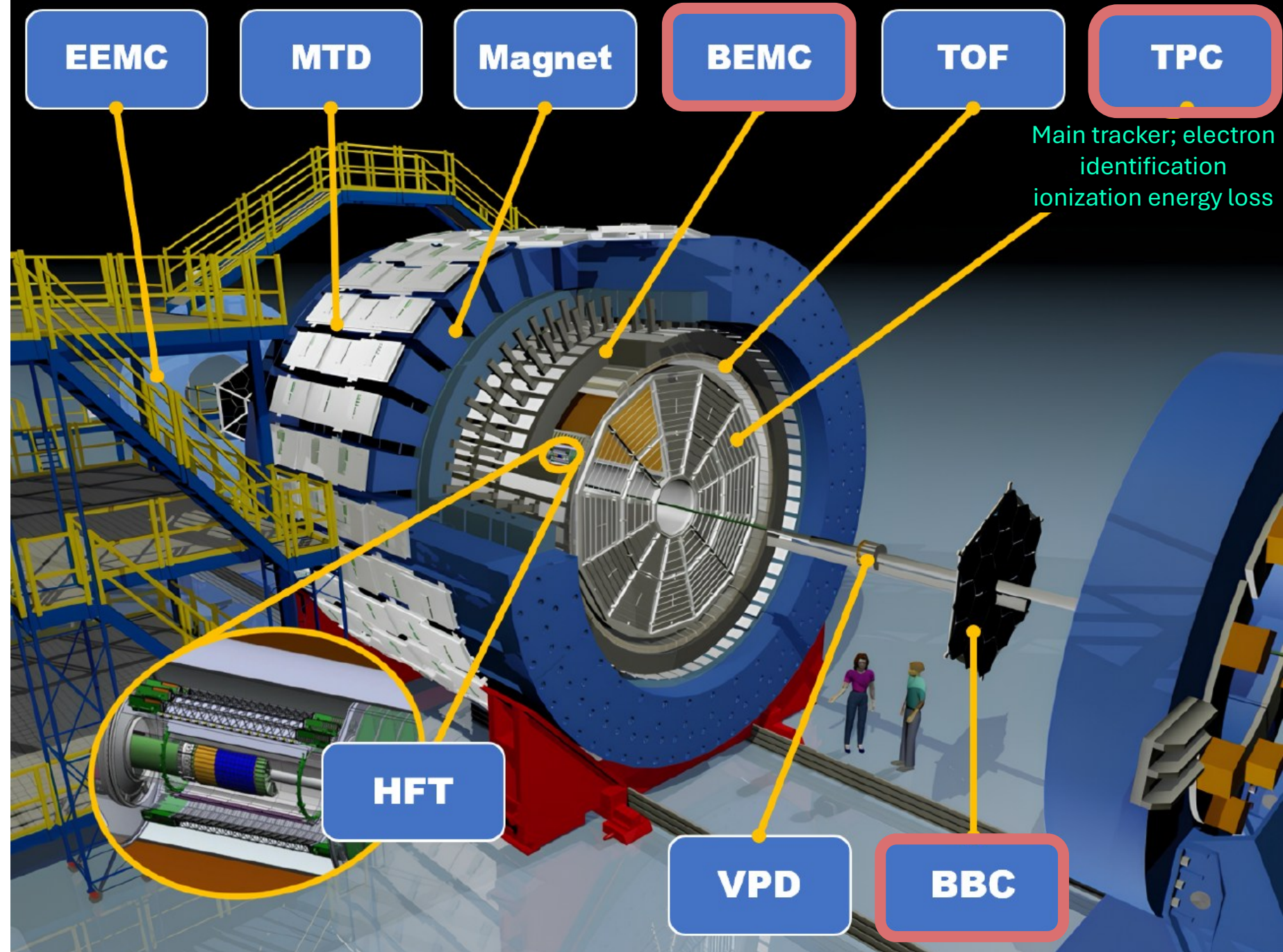


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Experiment and Dataset

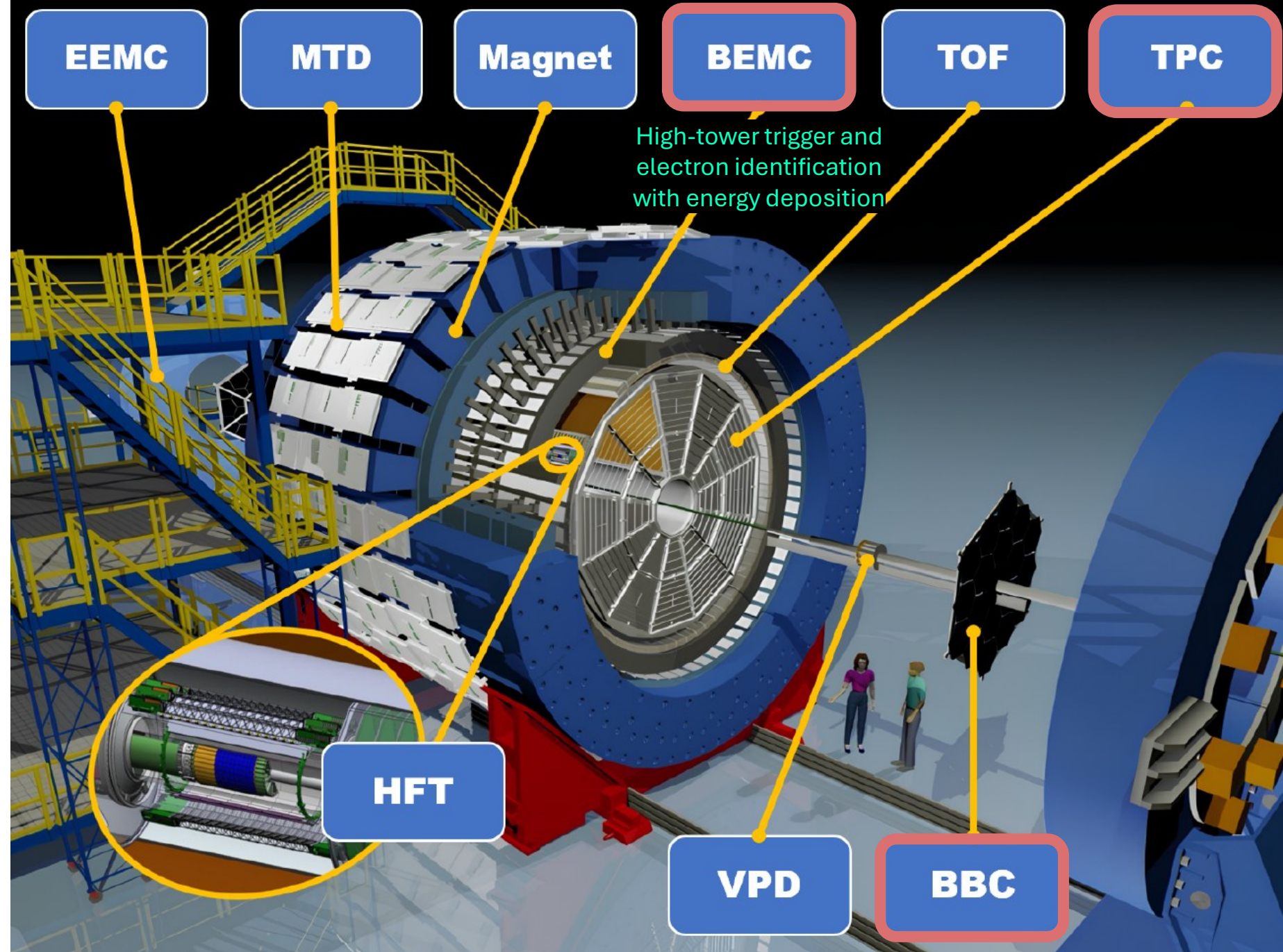
The STAR Experiment

(as in 2015)



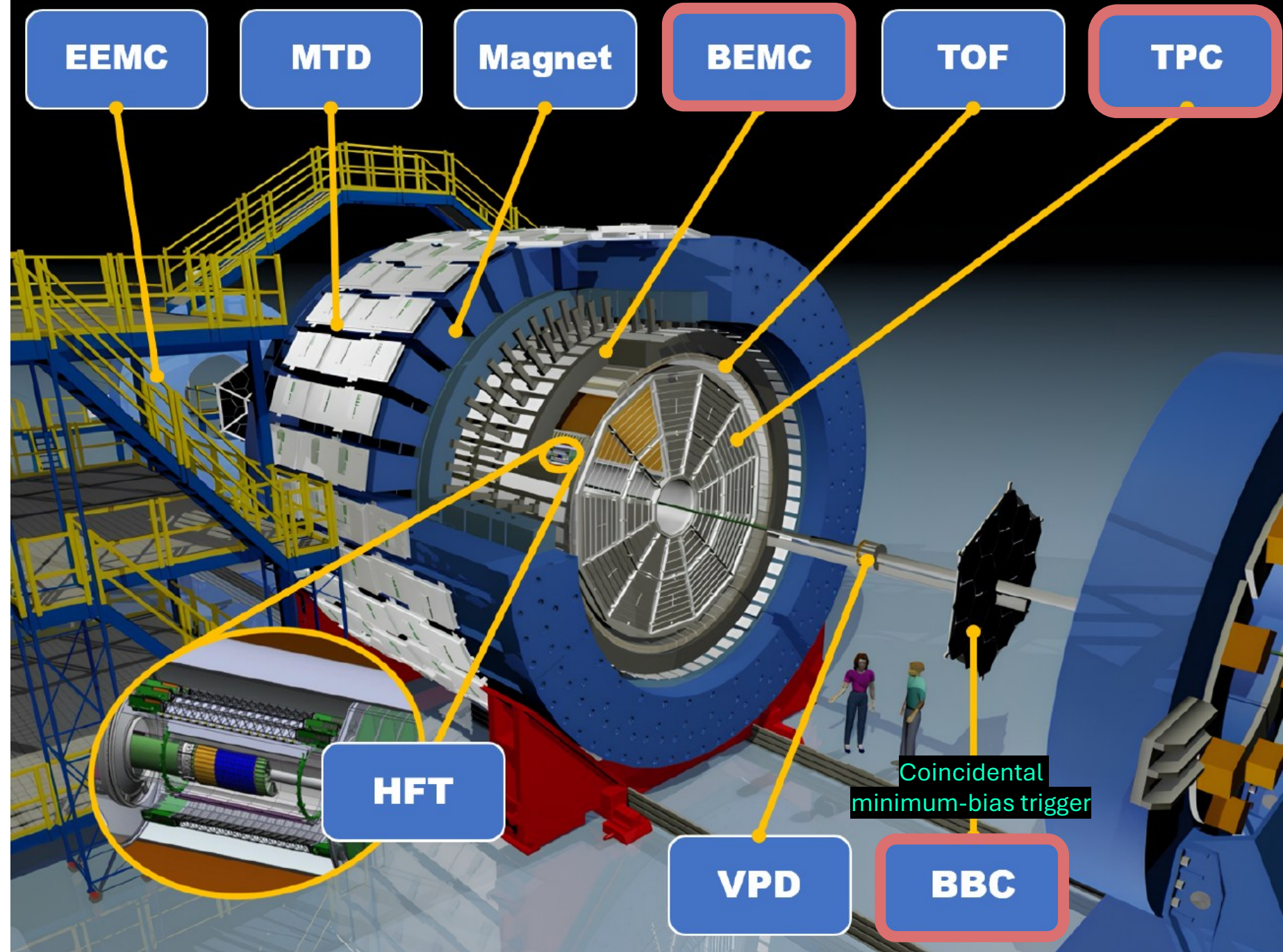
The STAR Experiment

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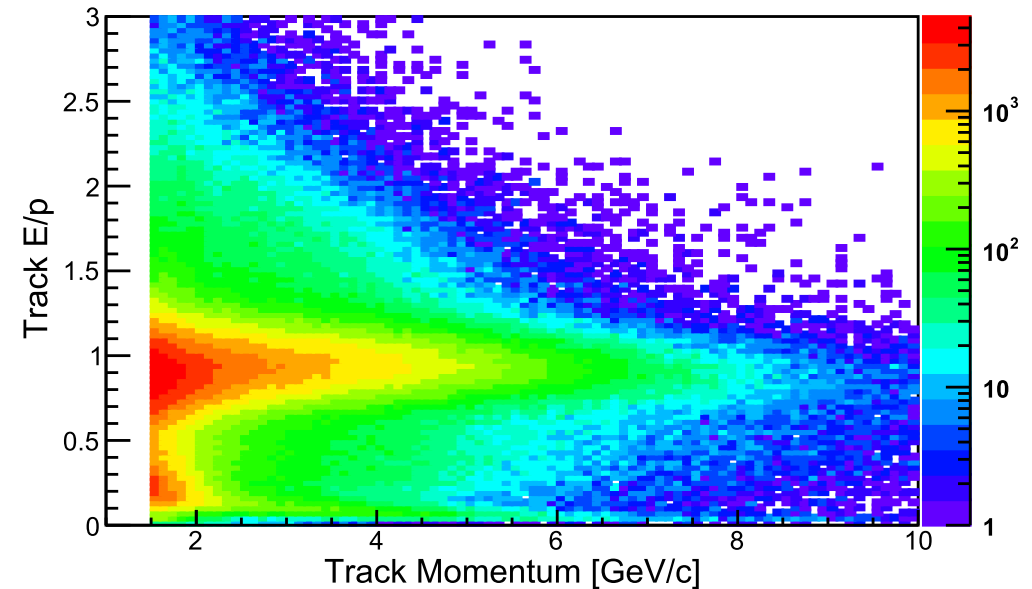
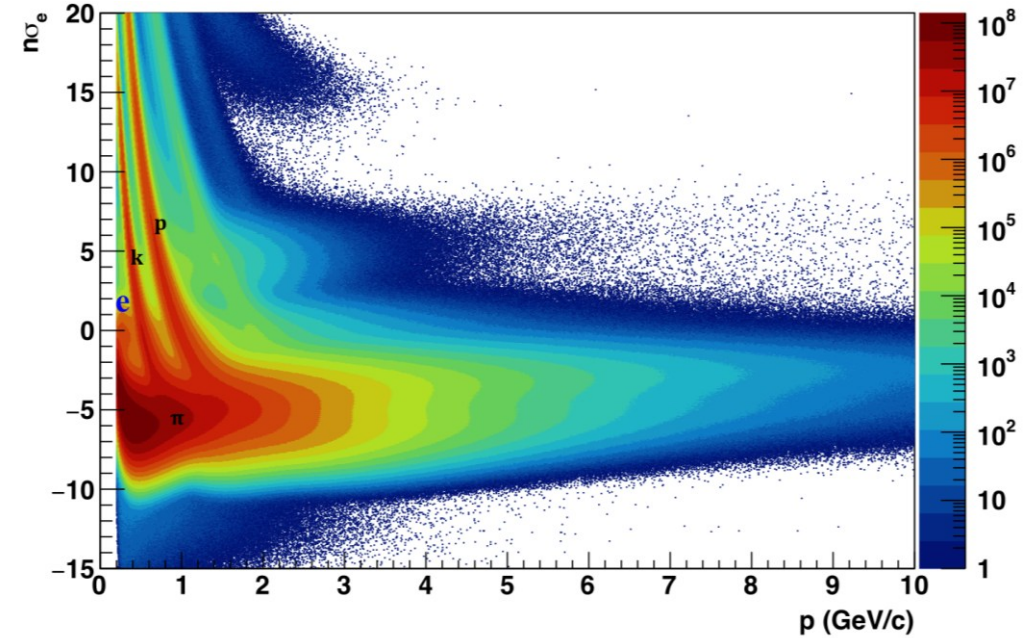


Dataset and Analysis Strategy

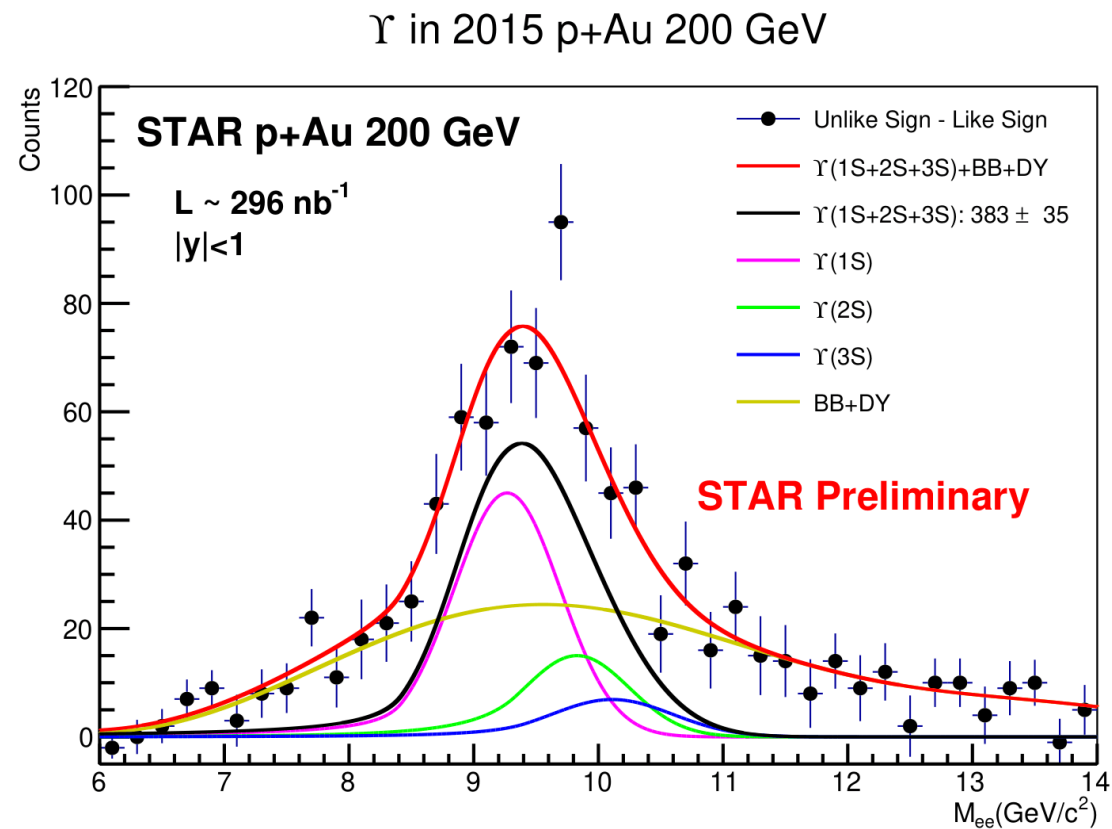
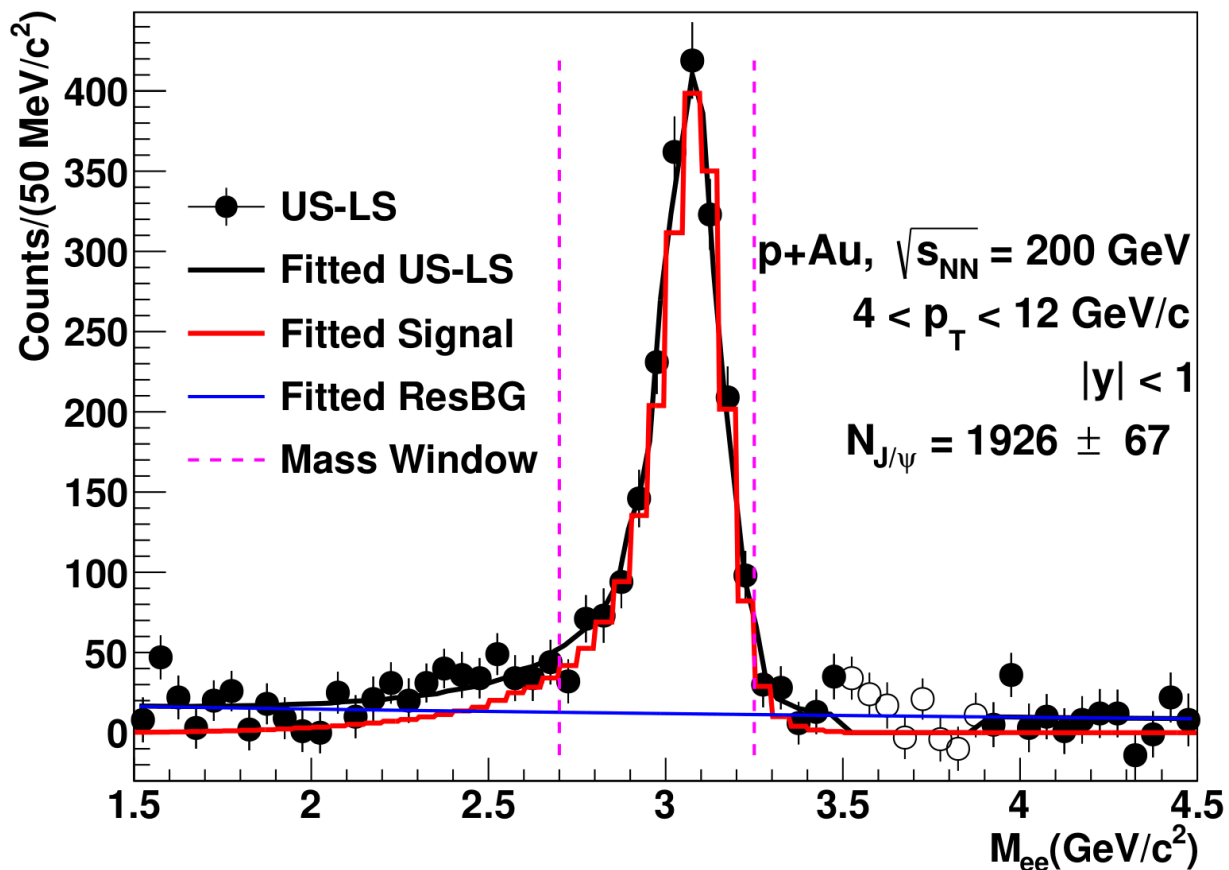
- Dataset: $p + p$ and $p + \text{Au}$ (2015)
- Reconstruction via decay channels:

$$J/\psi \text{ (or } \Upsilon) \rightarrow e^+ e^-$$

- $e^\pm$ identification
 - TPC with $n\sigma_e$
 - BEMC with E/p
 - Require both selections simultaneously



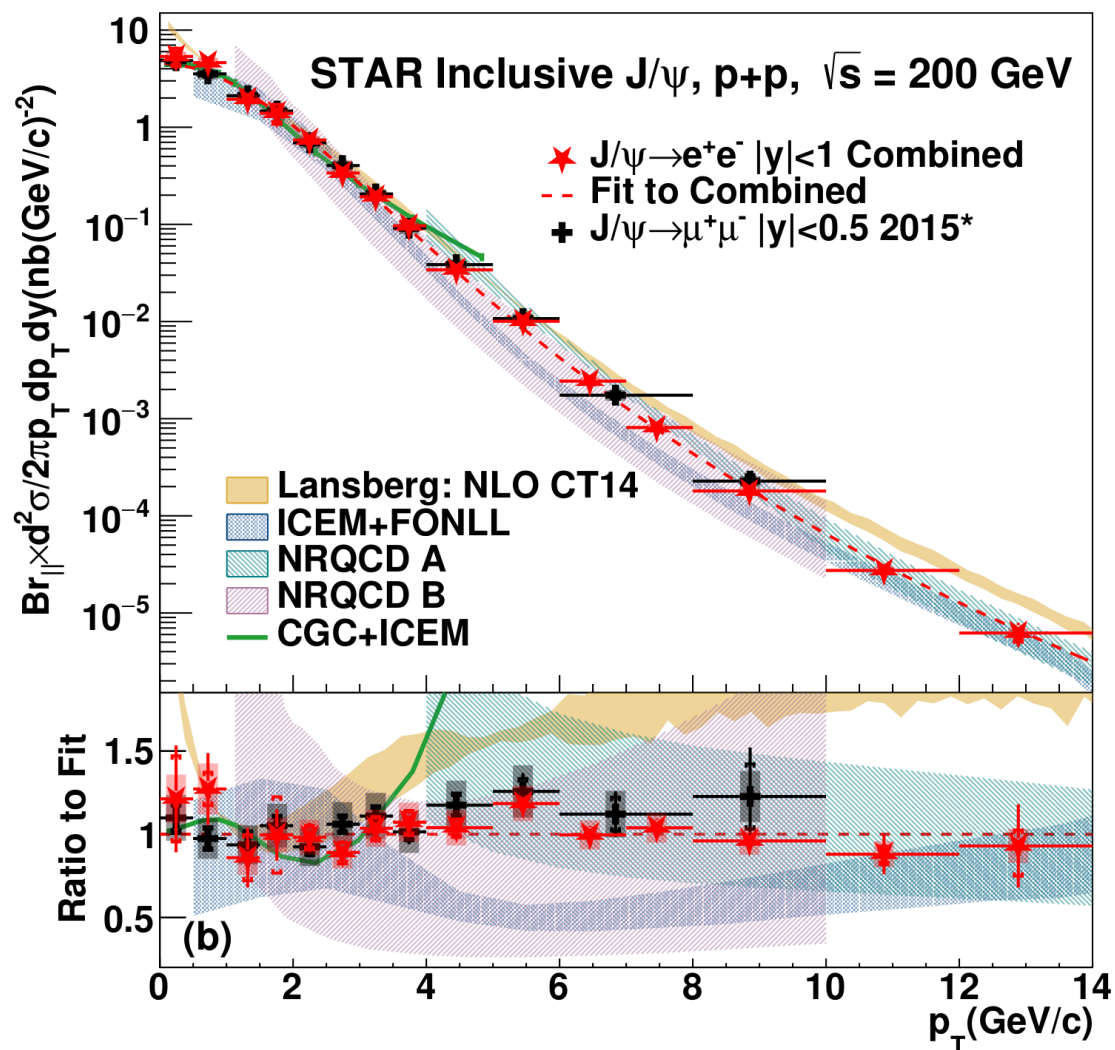
Signal Extraction for J/ψ and $\Upsilon(1S + 2S + 3S)$



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Results and Physics Discussion

Production of J/ψ in $p + p$ Collisions



Under journal review (arXiv:2604.22184)

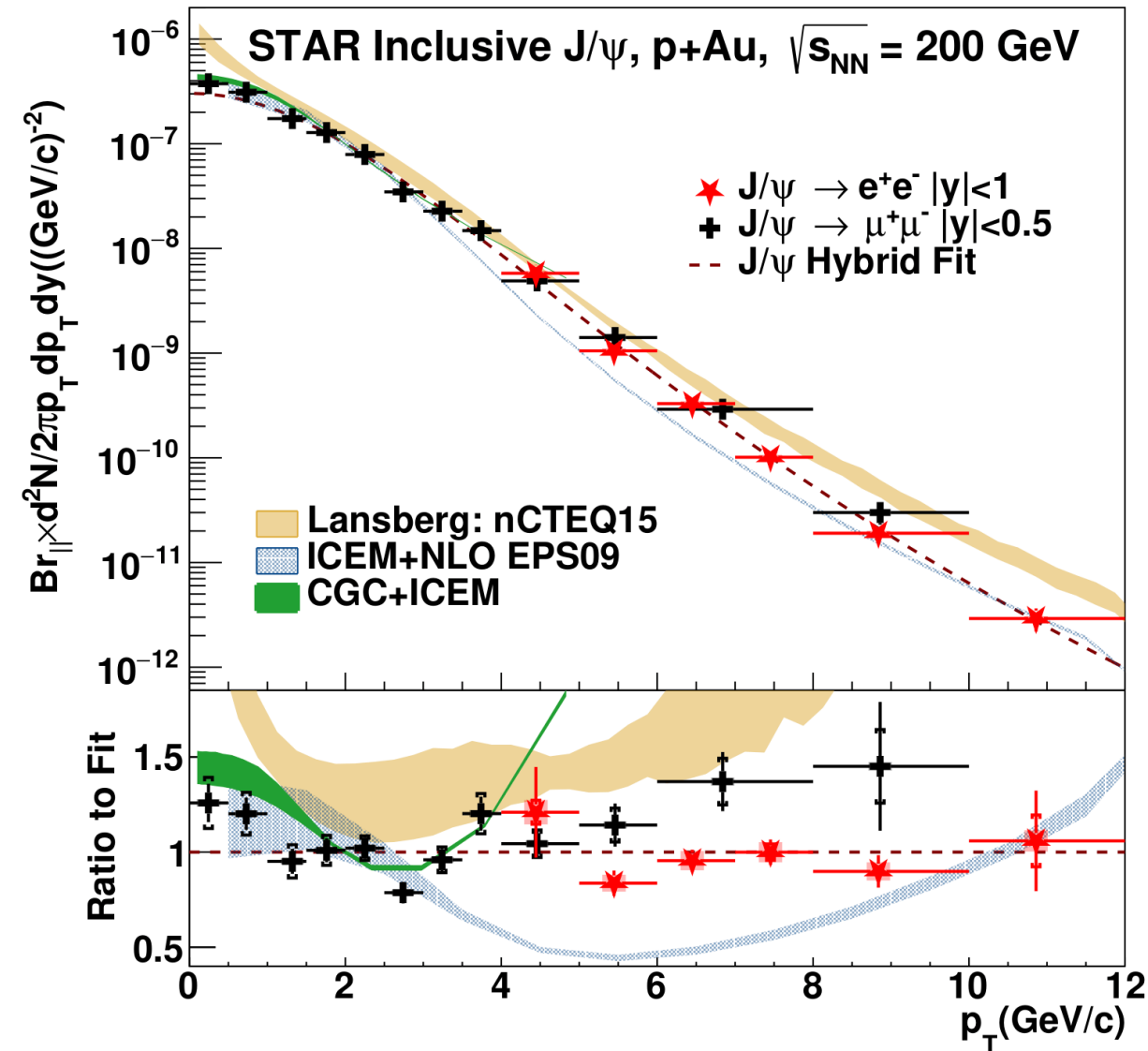
The dielectron $p + p$ cross section is a combined result, merging this analysis with two STAR's published measurements (using data taken in 2009, 2012)

- All calculations are consistent with measurements at low p_T , but raise tension at mid-to-high p_T

- Models: CGC is a small Bjorken- x effective theory
Constrained by published $p_T < 6$ GeV/ c data

- ICEM: fixed fraction of $c\bar{c}$ converted to J/ψ by pQCD
- CGC: gluon saturation
- Lansberg: NLO CT14 (PDF) + parton scattering amplitude
- FONLL: pQCD for heavy quarks
- NRQCD: pQCD + LDMEs

Production of J/ψ in $p + \text{Au}$ Collisions



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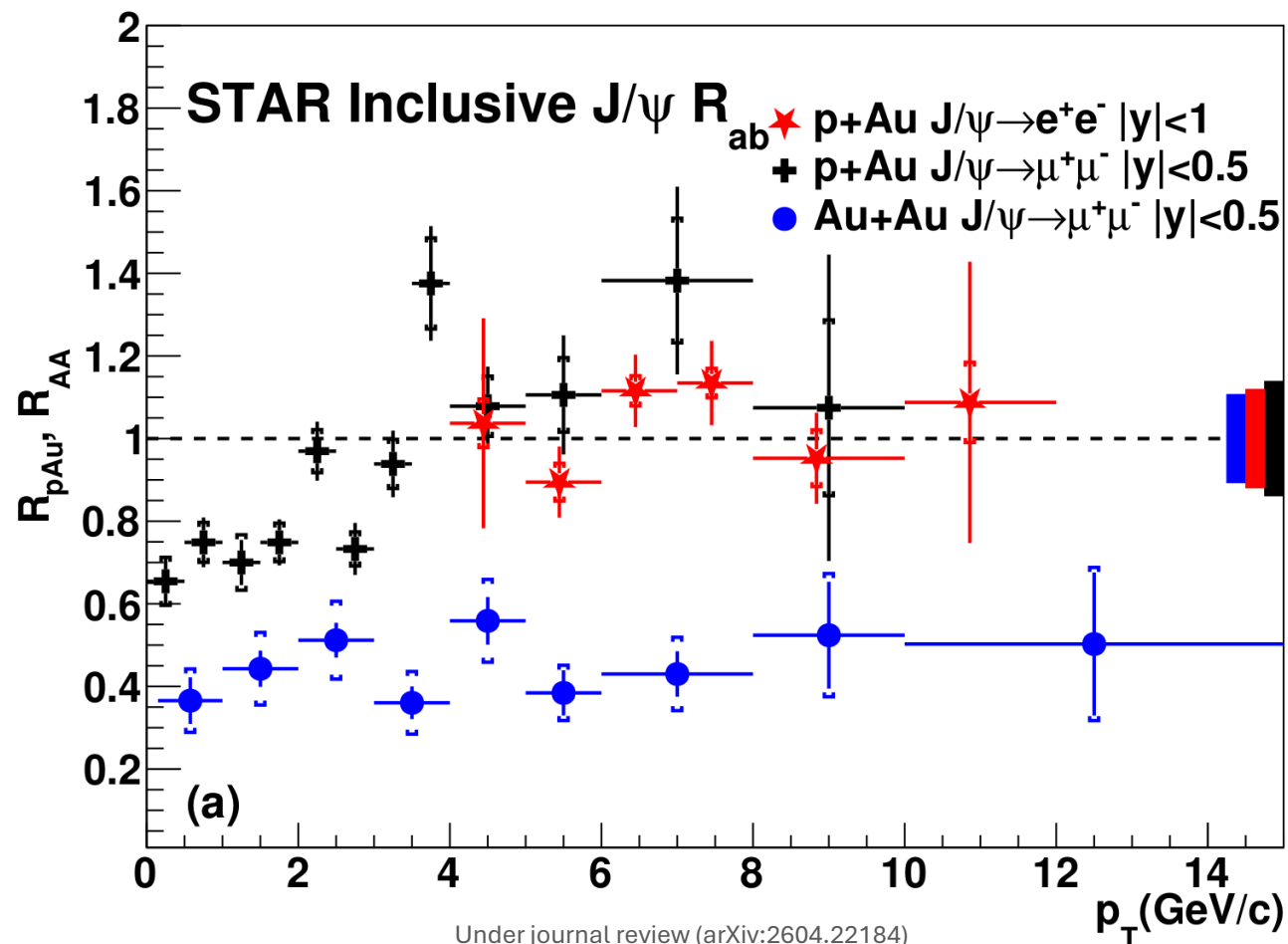
- Models:

■ ICEM, CGC...

■ Lansberg: nCTEQ15 (nPDF parameterization) + parton scattering amplitude

■ NLO EPS09: nPDF

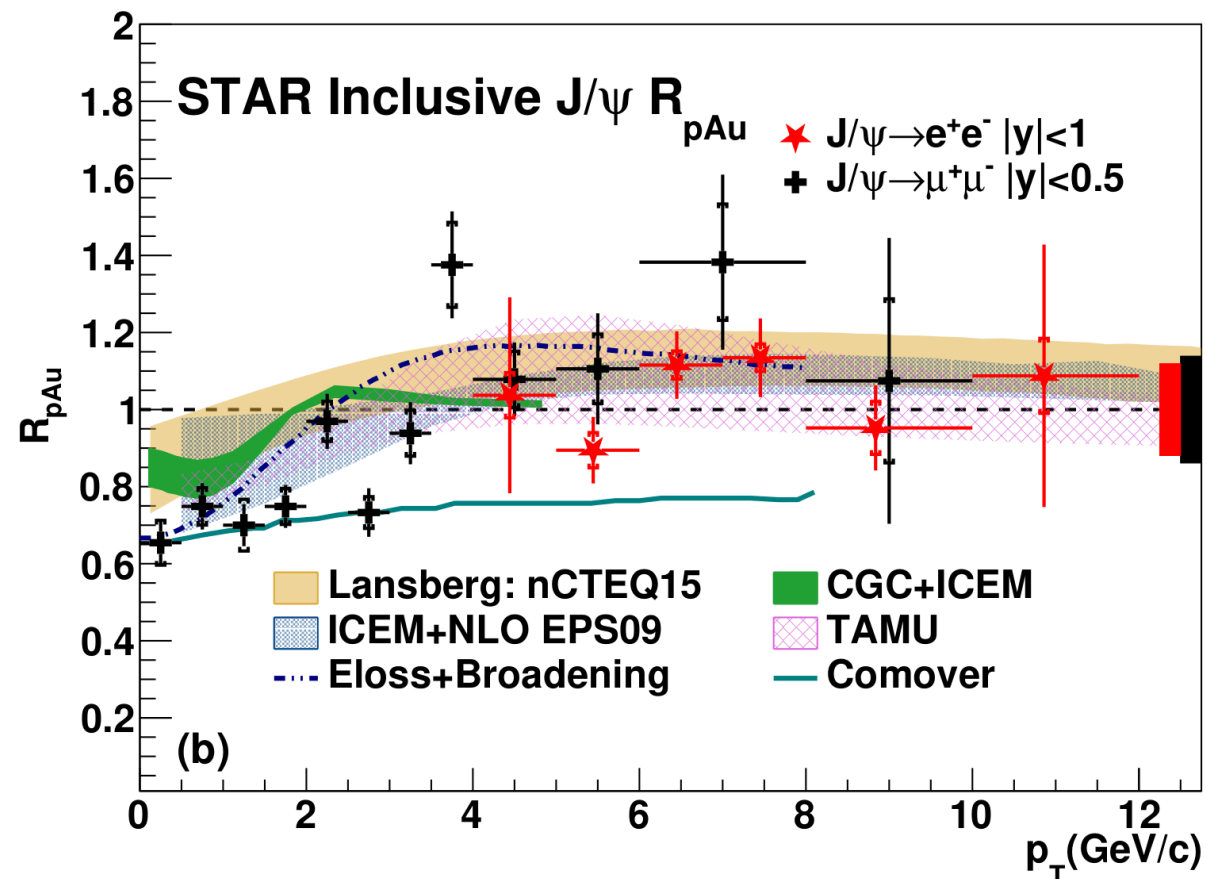
$R_{p\text{Au}}$ of J/ψ Production



● The $R_{p\text{Au}}$ is around unity at mid-to-high p_T

■ The suppression in $A - A$ at this range is most likely dominated by hot nuclear matter effects

R_{pAu} of J/ψ Production



Under journal review (arXiv:2604.22184)

“Comover” was formulated for low p_T

● All model calculations are compatible with the R_{pAu} measurement

■ “comover” model deviates from the data at $p_T > 3$ GeV

■ TAMU is not deferred by data

● Models:

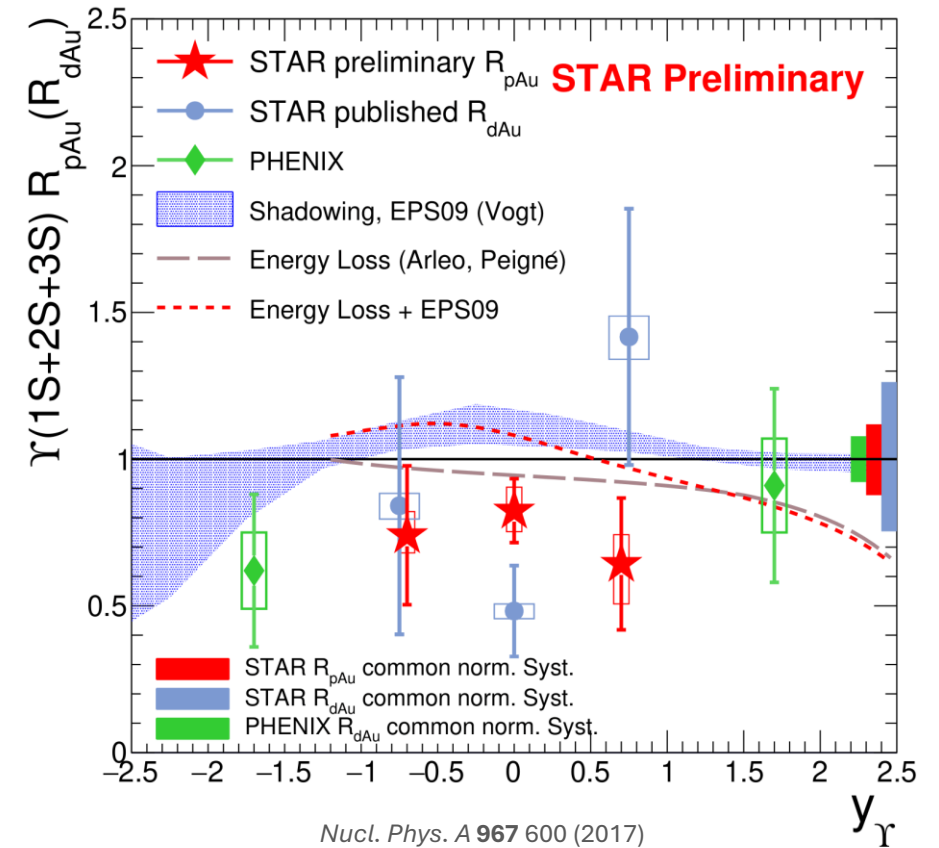
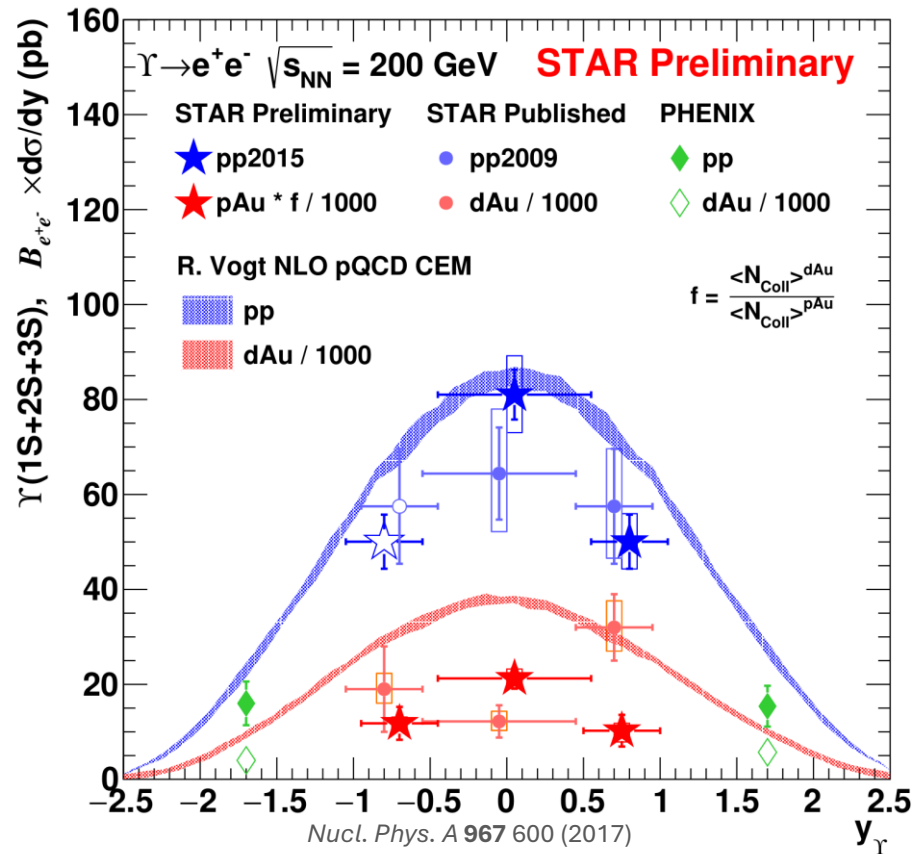
■ Lansberg, ICEM, CGC, NLO EPS09...

■ TAMU: nPDF + transport model (short lived hot medium)

■ “Eloss+Broadening”

■ “Comover”: with EPS09

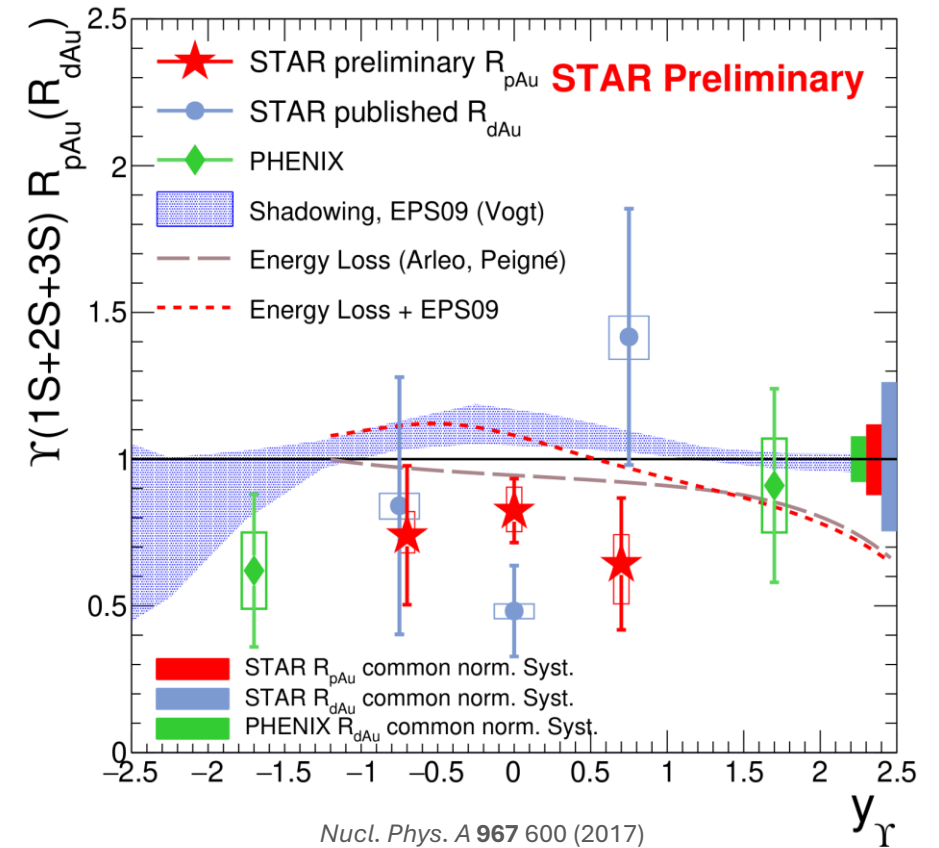
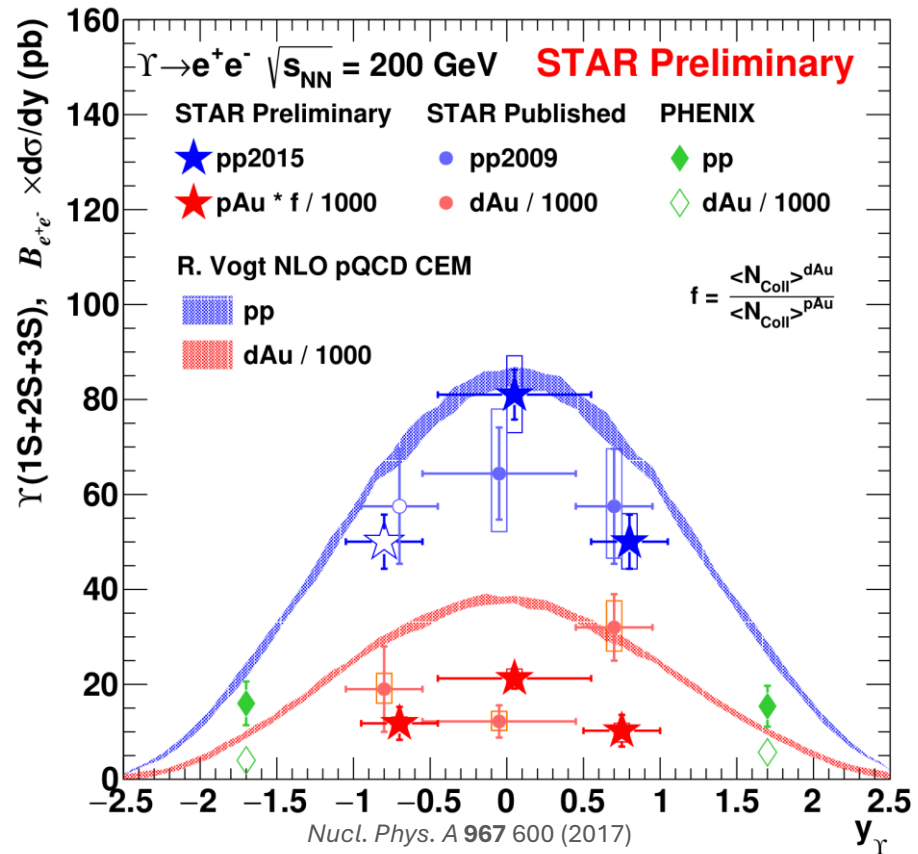
Measurements of $\Upsilon(1S + 2S + 3S)$ Production



- NLO pQCD CEM for $p + p$: overestimates when moving away from the mid-rapidity range
- NLO pQCD CEM for $p + Au$: overestimates at mid rapidity

- Measurement of R_{pAu} of $\Upsilon(1S + 2S + 3S)$ shows suppression, disagrees with nPDF, Energy Loss or NLO pQCD CEM calculation alone
- Suggest other effects

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 - Suggest other effects – **Cold**, **hot**, or **both**?

Summary

J/ψ production in $p + p$ and $p + \text{Au}$ collisions

- In both collision systems, models are **consistent** with measured invariant yield **at low p_T** , while **raise tension at mid-to-high p_T**
- Models are consistent with measured $R_{p\text{Au}}$
 - New results will constrain the models in invariant yield
 - TAMU is not deferred by data

$\Upsilon(1S + 2S + 3S)$ production in $p + p$ and $p + \text{Au}$ collisions

- CEM **overestimates the yield** in both collisions systems
- nPDF and/or Energy Loss models (and the CEM) overestimates the $R_{p\text{Au}}$
 - Suggests other effects – **Cold**, **hot**, or **both**?



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Thanks for your attention!



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Backup: Model Calculation Details

Model	References	Main Uncertainty Sources
Lansberg: NLO CT14 and nCTEQ 15	<i>Eur. Phys. J. C</i> 77 , 1 (2016) <i>Phys. Rev. Lett.</i> 121 , 052004 (2018) <i>Comput. Phys. Commun.</i> 184 , 2562 (2013) <i>Comput. Phys. Commun.</i> 198 , 238 (2016)	factorization scale, PDF
ICEM	<i>Phys. Rev. D</i> 94 , 114029 (2016)	charm quark mass, factorization, renormalization
FONLL	<i>J. High Energy Phys.</i> 1998 , 007 (1998) <i>J. High Energy Phys.</i> 2001 , 006 (2001)	
NRQCD	<i>Phys. Rev. D</i> 84 , 114001 (2011) <i>Phys. Rev. Lett.</i> 108 , 172002 (2012)	
CGC	<i>Phys. Rev. C</i> 97 , 014909 (2018)	$\langle \bar{p} \rangle$ of soft color exchanges, saturation scale difference between p vs. Au
TAMU	<i>Nucl. Phys. A</i> 943 , 147 (2015)	nPDF, p_T broadening parameterization, formation time of J/ψ
Eloss+Broadening	<i>J. High Energy Phys.</i> 2013 , 155 (2013)	Not estimated
Comover	<i>Phys. Lett. B</i> 749 , 98 (2015)	Not estimated
NLO pQCD CEM	<i>Phys. Rept.</i> 462 , 125 (2008)	feed-down contributions, factorization scales, Renormalization, LDMEs
Eloss+EPS09	<i>J. High Energ. Phys.</i> 2013 , 122 (2013)	Not estimated