Charmonium production in isobaric collisions at 200 GeV with the STAR experiment

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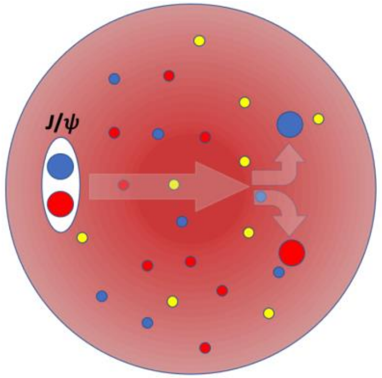
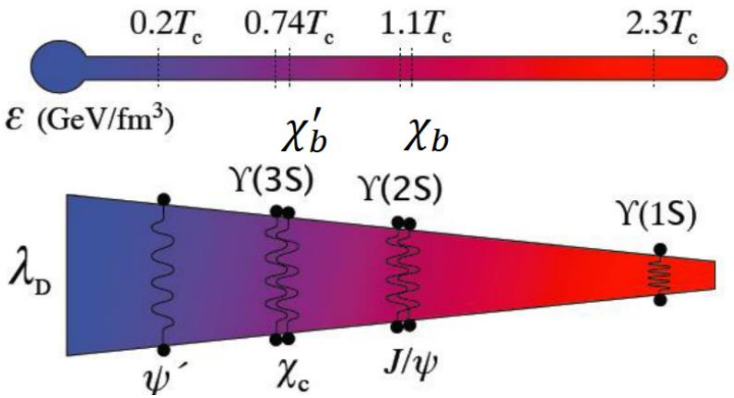
Introduction

- Quarkonium provides a good probe of the Quark-Gluon Plasma (QGP)

Dissociation → sequential suppression



Credit: Q. Yang

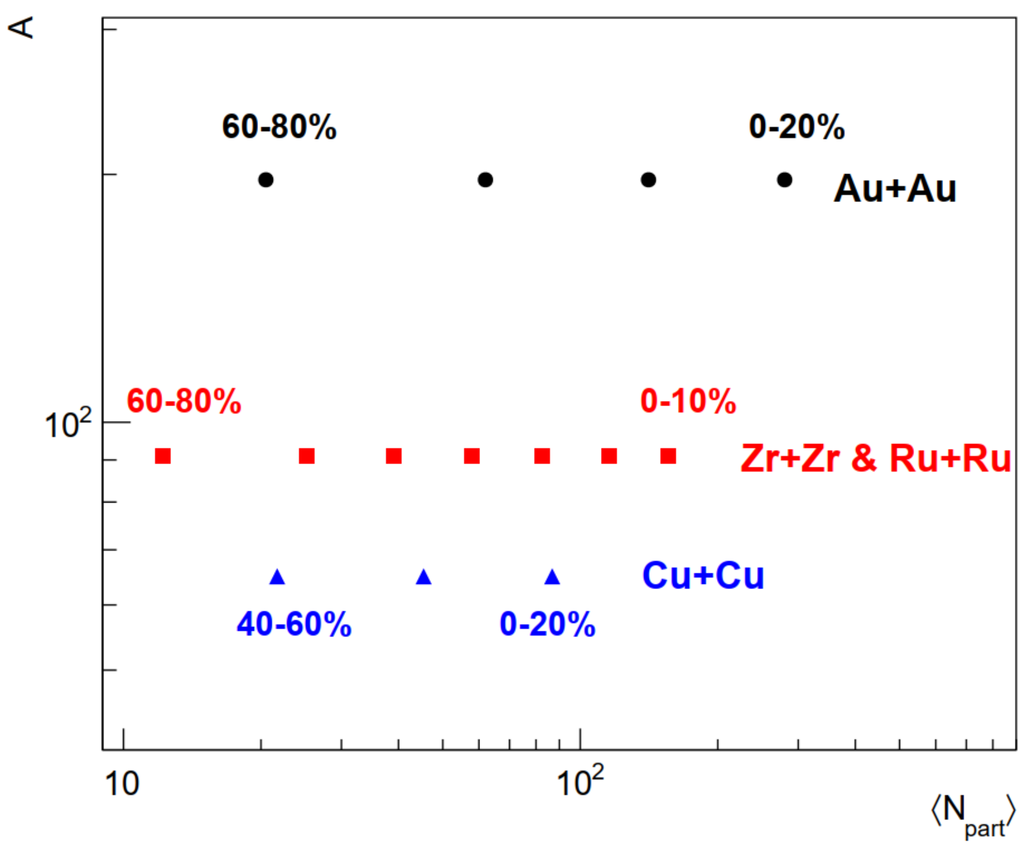


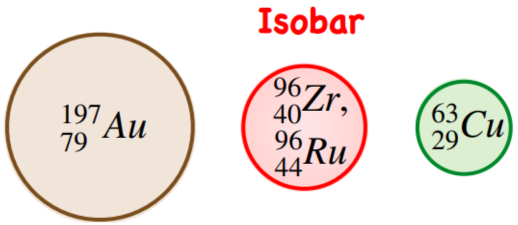
S. Diagl, P. Petreczky and H. Satz, PLB514, 57 (2001)

- Other effects:
  - Regeneration
  - Cold nuclear matter effects
  - Feed down

- Systematically analyze
  - Different quarkonia
  - System size dependence
  - Transverse momentum dependence
  - Centrality dependence

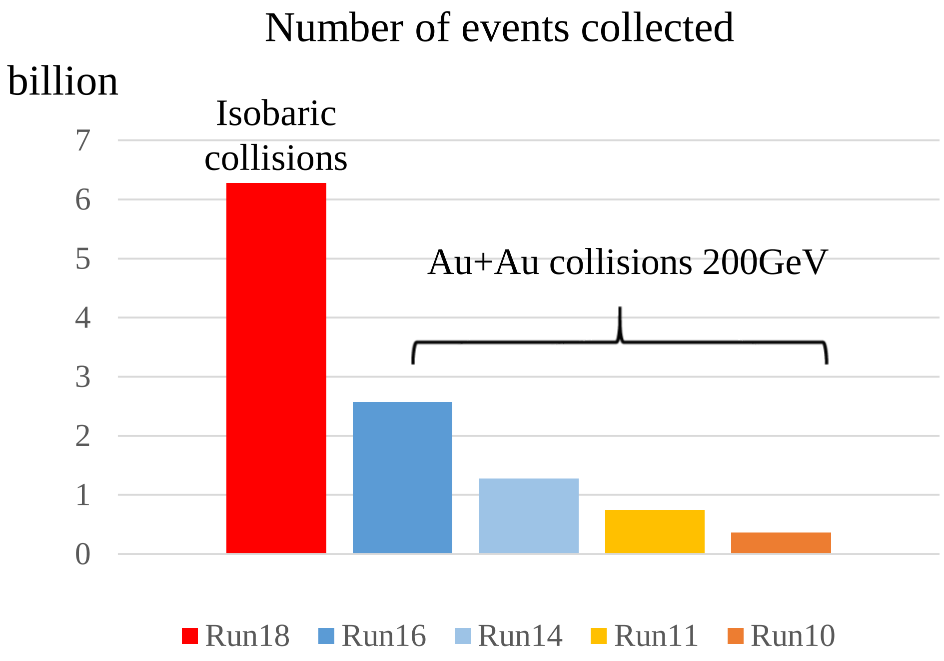
Isobaric collisions



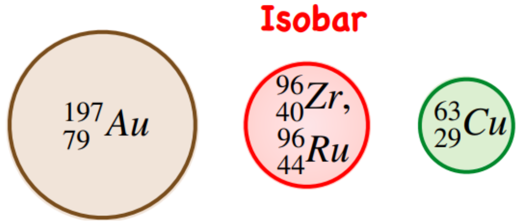


- A moderate size collision system
  - All these effects are expected to show strong dependence on collision system size
  - Unique opportunity to study the system size dependence

Isobaric collisions

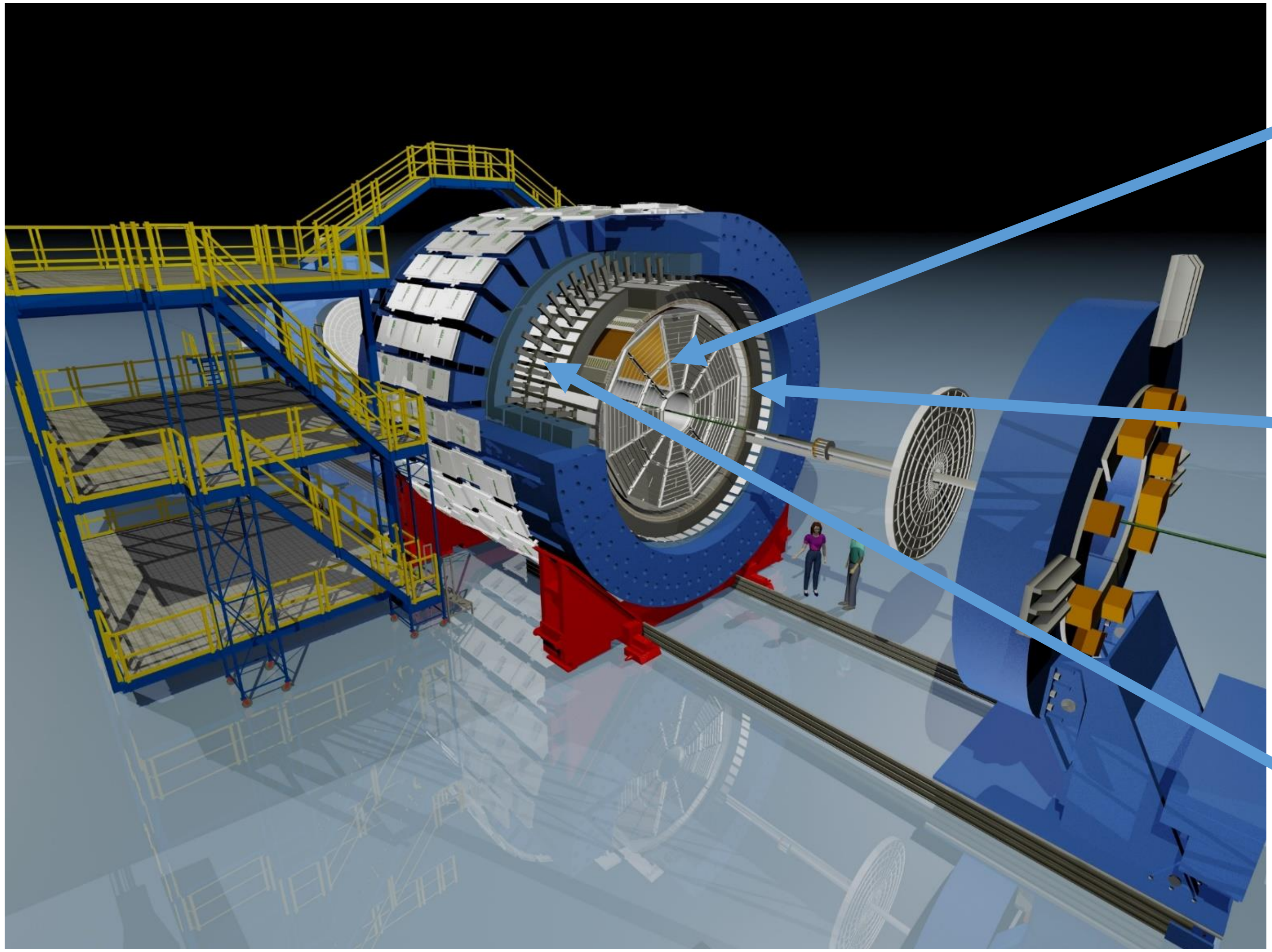


6B minimum bias events



- Large isobar sample
  - Precise p_T spectra can deepen our understanding of these effects by giving theoretical models stronger constraints
  - Unique opportunity to study ψ(2S)-to-J/ψ yield ratio

The Solenoidal Tracker At RHIC



✓ **TPC**

Tracking, momentum and energy loss

Acceptance: $|\eta| < 1$; $0 \leq \varphi < 2\pi$

✓ **TOF**

Time of flight, particle identification

Acceptance: $|\eta| < 1$; $0 \leq \varphi < 2\pi$

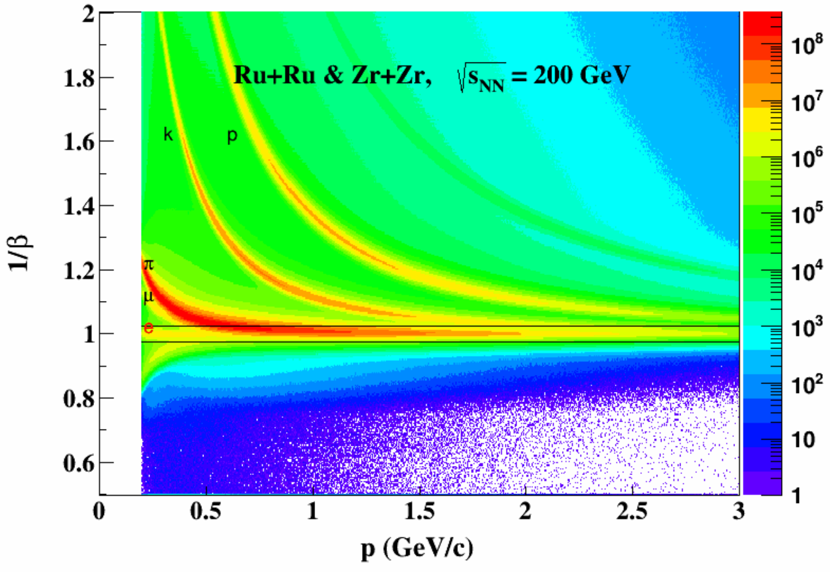
✓ **BEMC**

$e^{\pm}$ trigger and identification

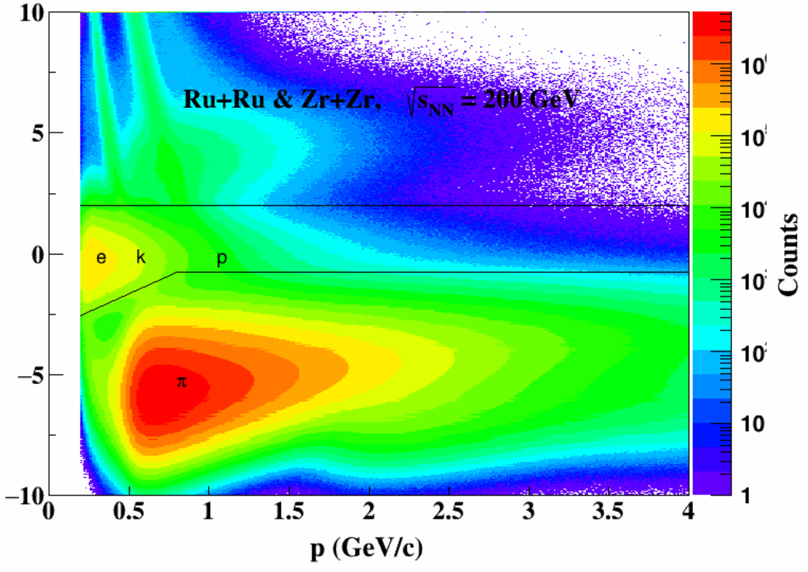
Acceptance: $|\eta| < 1$; $0 \leq \varphi < 2\pi$

Electron identification

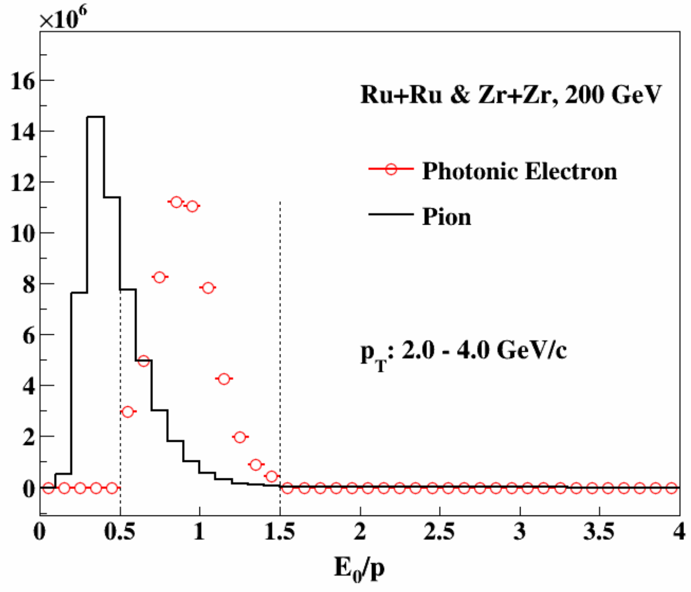
TOF PID



TPC PID after TOF cut



BEMC PID cuts

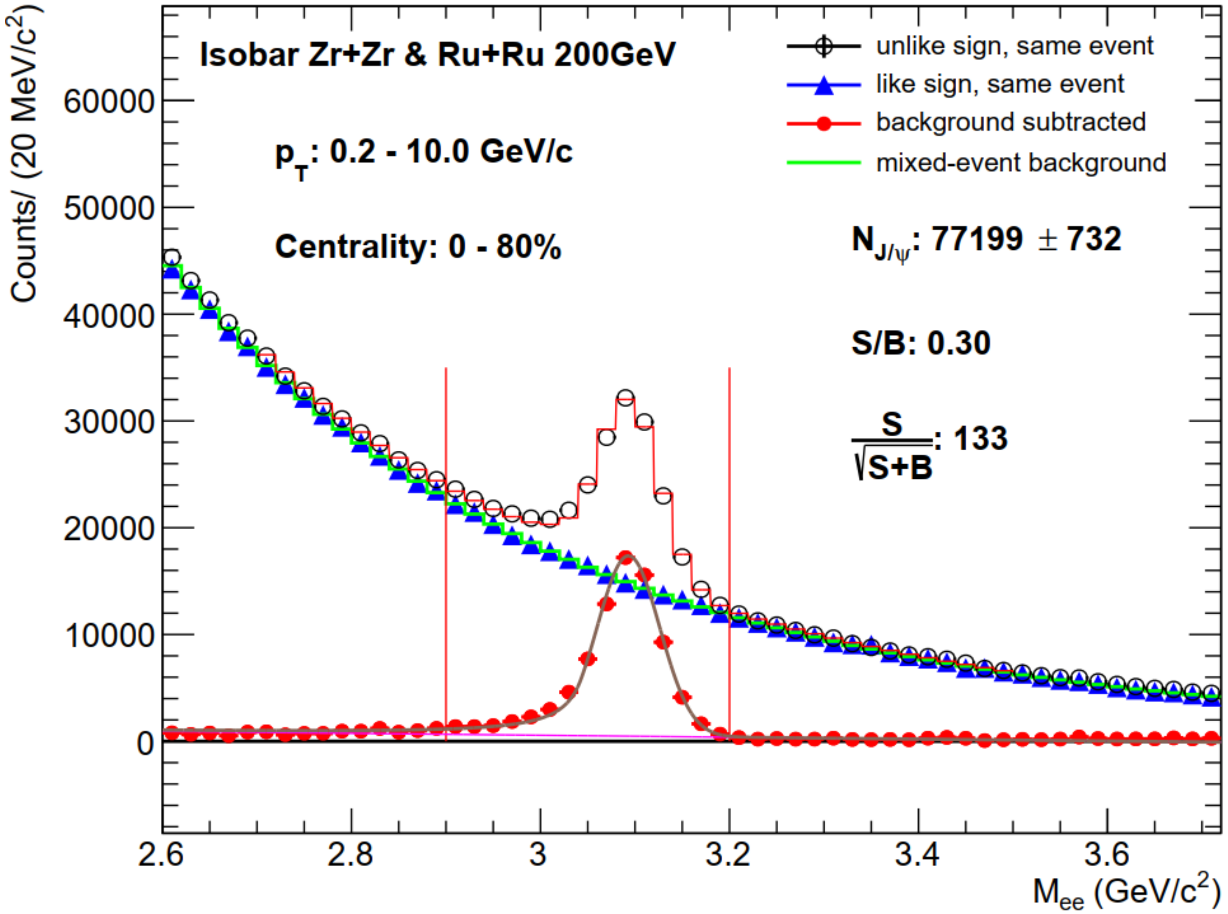


- TPC, TOF, and BEMC used to identify electron

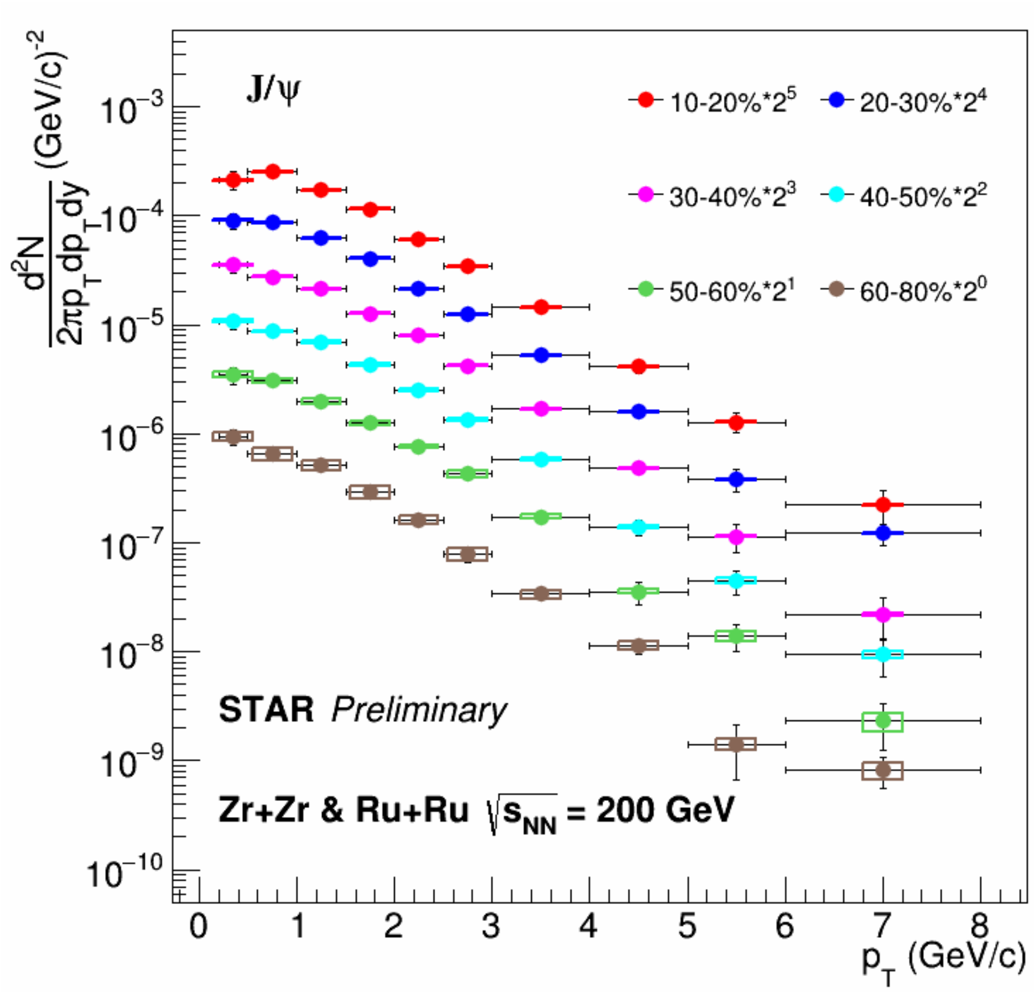
- TPC: $n\sigma_e$
- TOF: $\frac{1}{\beta}$
- BEMC: $\frac{E_0}{p}$

J/ψ signal in Zr+Zr & Ru+Ru collisions

- Fit unlike-sign invariant mass distribution:
  - J/ψ signal – crystal ball function from embedding
  - Combinatorial background – Mixed-event technique
  - Residual background – linear function



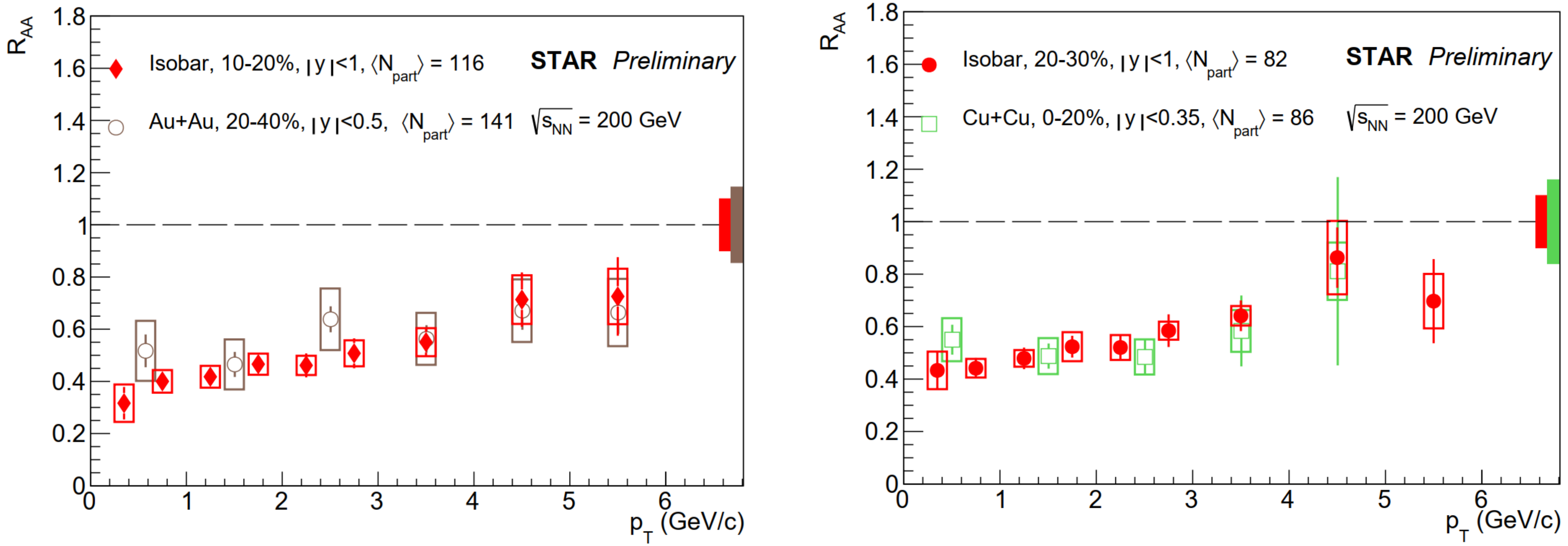
J/ψ spectra



- Precise J/ψ spectra are obtained at 0.2-8 GeV/c p_T range.
- Nuclear modification factor (R_{AA}) is defined as:

$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \times \frac{\left(\frac{d^2 N_{J/\psi}}{2\pi p_T dp_T dy}\right)_{A+A}}{\left(\frac{d^2 N_{J/\psi}}{2\pi p_T dp_T dy}\right)_{p+p}}$$

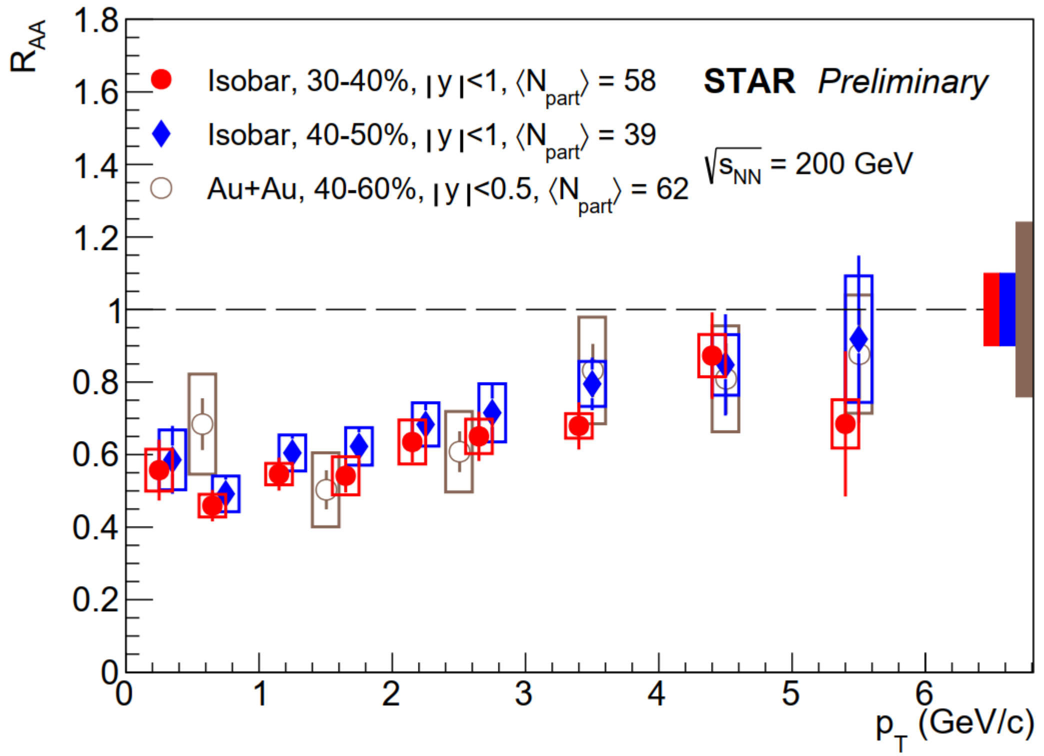
Nuclear modification factors

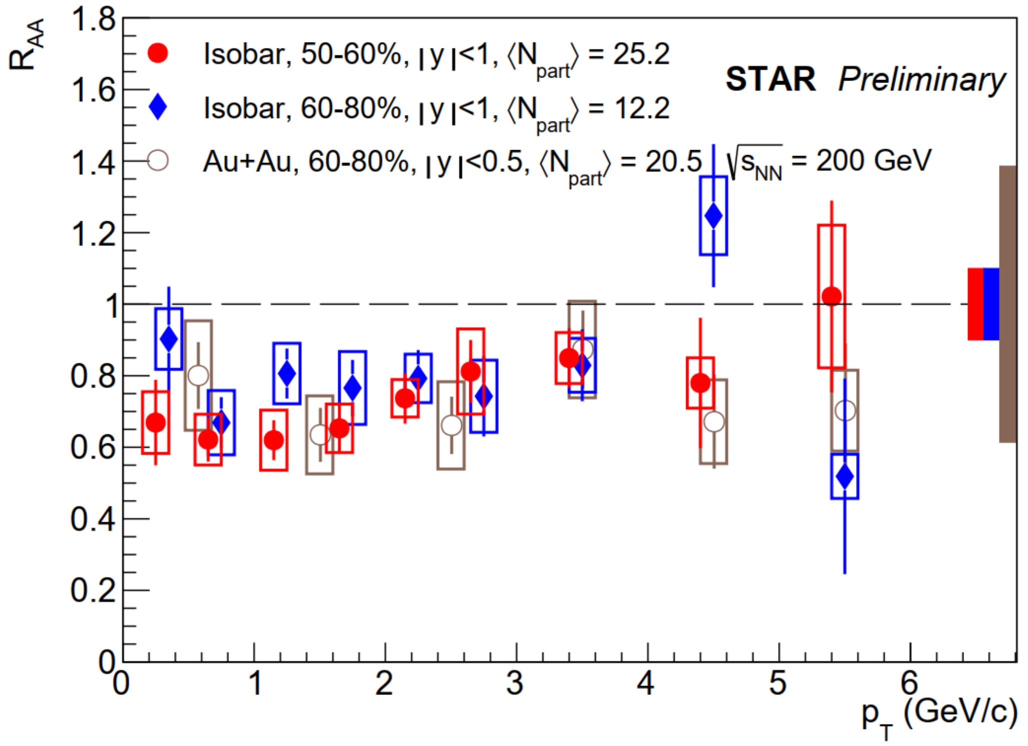


STAR, PLB 797, 134917,2019
PHENIX,PRL101, 122301 ,2008

- Central and mid-central collisions
  - High-precision J/ψ measurement at RHIC
  - Significant suppression observed
  - Consistent with Au+Au and Cu+Cu results for similar ($\langle N_{part} \rangle$)

Nuclear modification factors

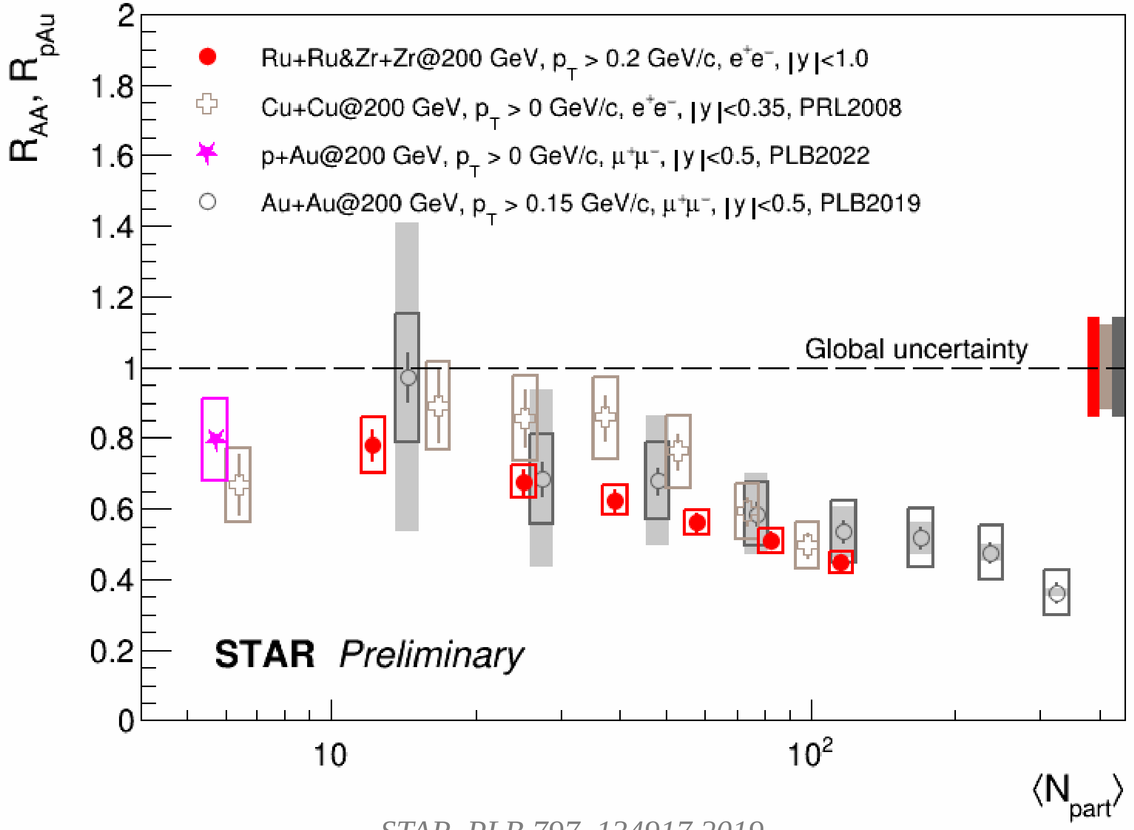




STAR, PLB 797, 134917,2019
PHENIX,PRL101, 122301 ,2008

- Peripheral collisions
  - Significant suppression observed at low-p_T range
  - Consistent with Au+Au results for similar ($\langle N_{part} \rangle$)

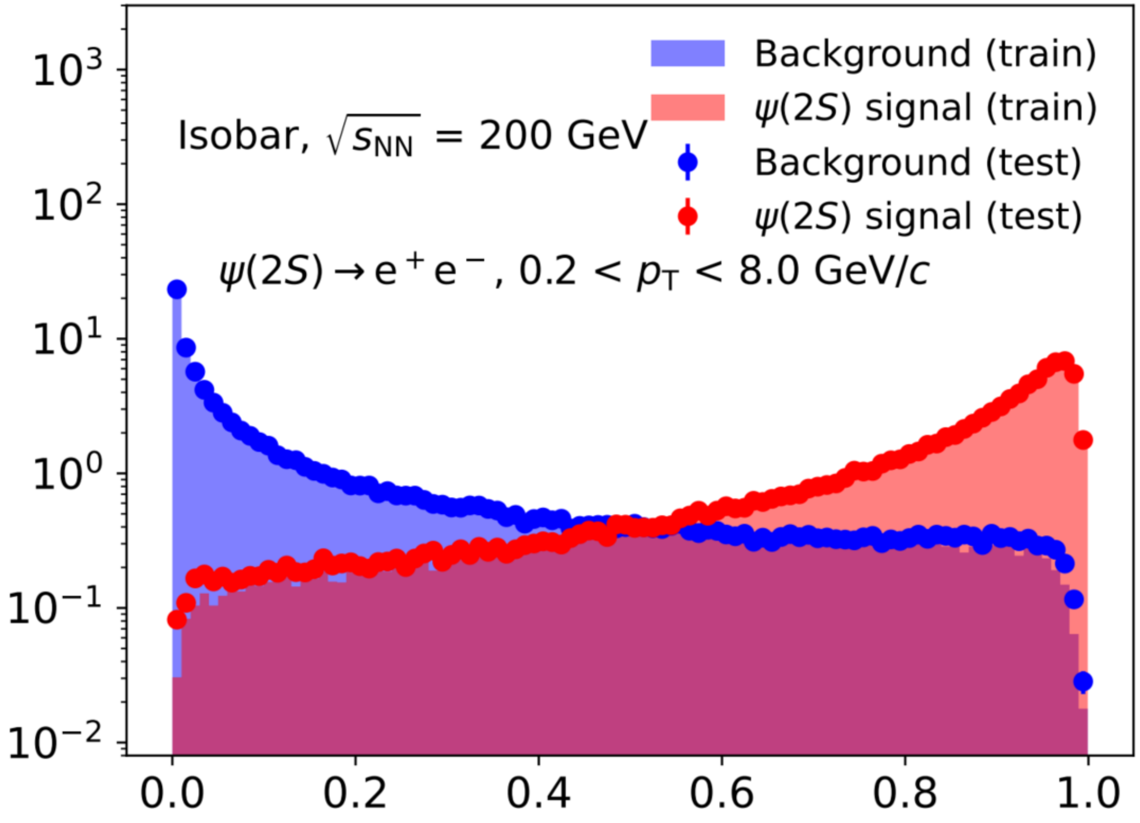
Nuclear modification factors



STAR, PLB 797, 134917,2019
PHENIX,PRL101, 122301 ,2008

- A decreasing trend with increasing $\langle N_{part} \rangle$ is observed
- Significant suppression observed at large $\langle N_{part} \rangle$ due to dissociation
- No significant collision system size dependence at RHIC energies

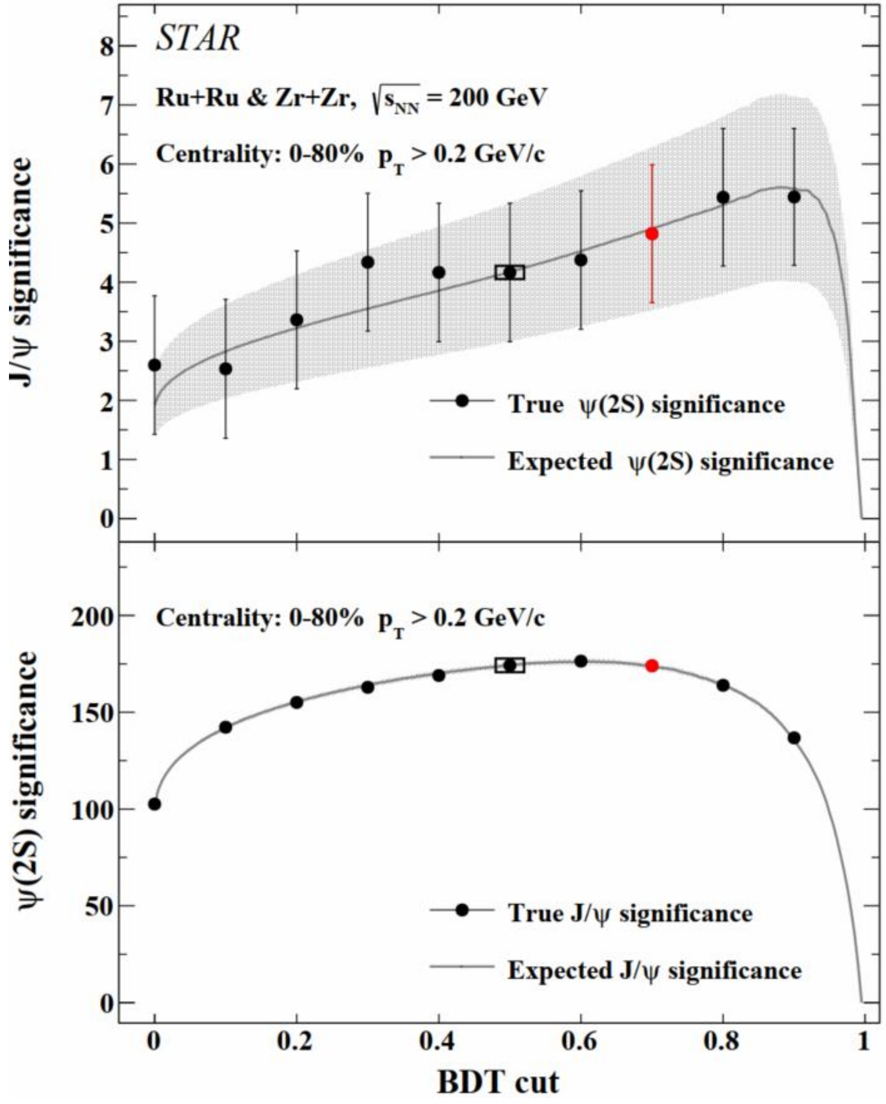
ψ(2S) signal in Zr+Zr & Ru+Ru collisions



BDT Output

- A machine learning method is employed to reconstruct the ψ(2S) signal
- XGBoost (Extreme Gradient Boosting) as core
- The consistency between training and testing data
  - Negligible overtraining

Determining the Working Point



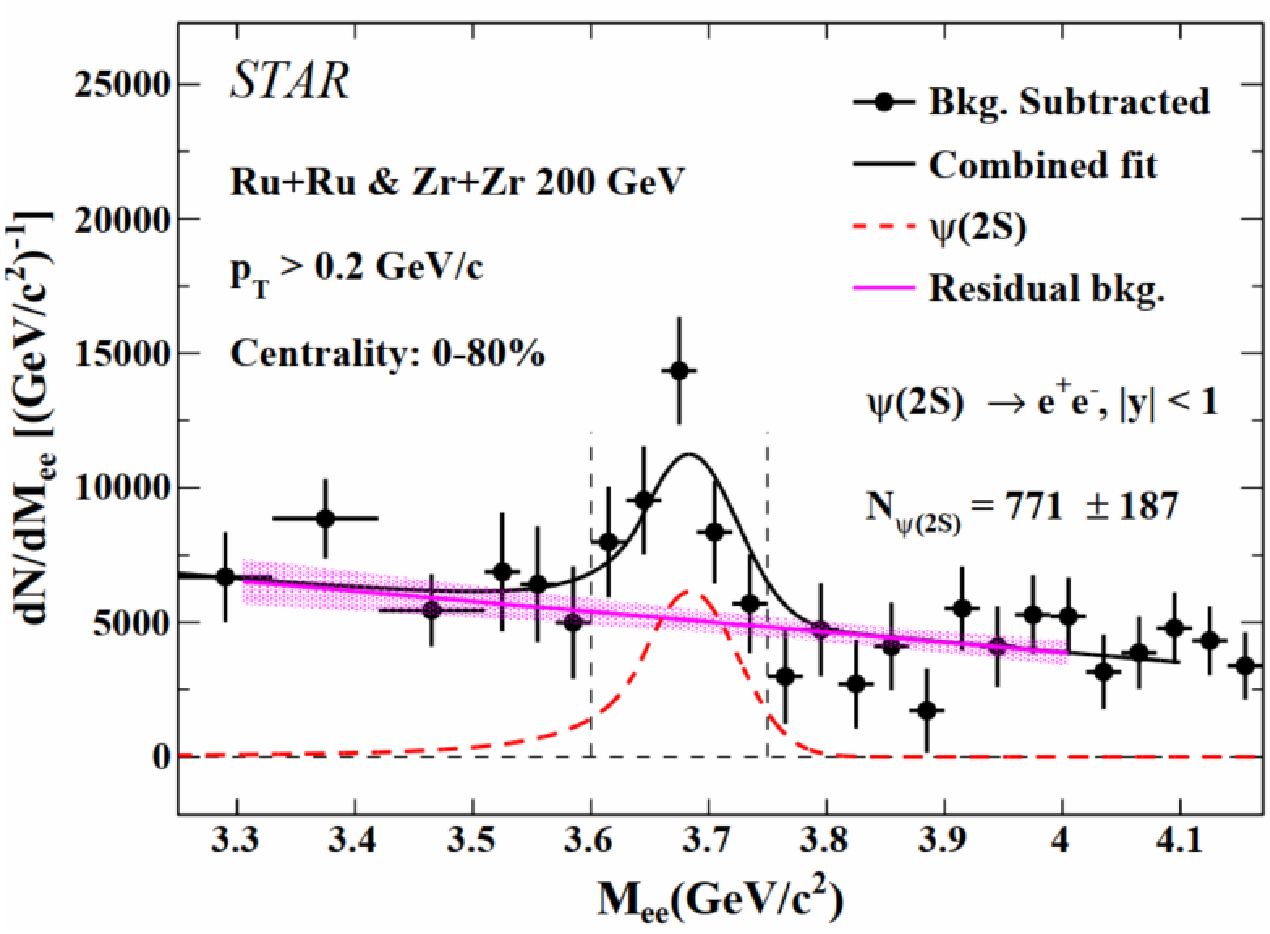
- ➢The expected significant is consistent with true significant
  - The feasibility of the machine learning process
- ➢The default BDT cut (Working Point) is determined by
  - The trend of the expected significant as a function of BDT cut
  - Systematic uncertainties stem form the selection of BDT cut

ψ(2S) signal in Zr+Zr & Ru+Ru collisions

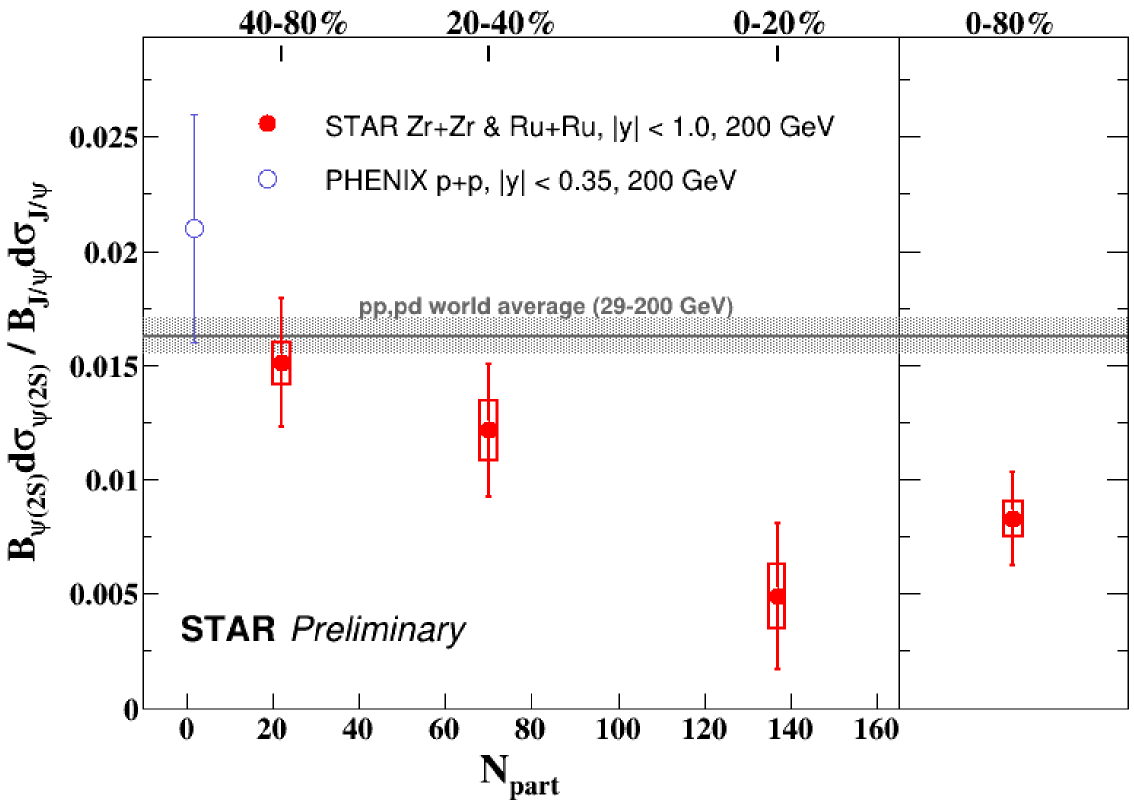
- Fit unlike-sign invariant mass distribution after combinatorial background subtracted (mixed event):

  - ψ(2S) signal – simulation and J/ψ signal

  - Residual background – linear function



ψ(2S) to J/ψ ratio in Zr+Zr & Ru+Ru collisions

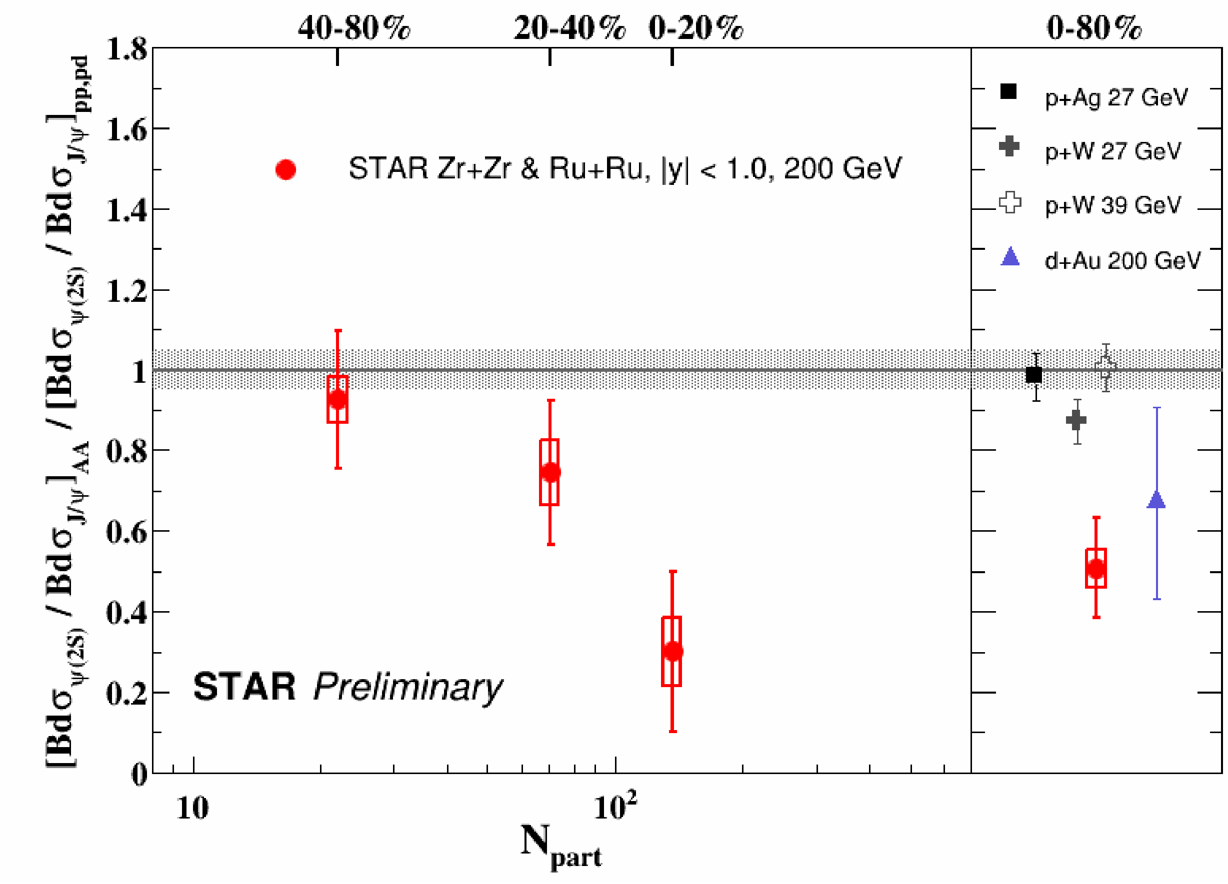


pp reference is the average of measurements in p+p(d) by NA51, ISR and PHENIX

PHENIX, Phys.Rev.D, 85,092004 (2012)
NA51, Phys.Lett.B 438 (1998) 35-40
ISR, Nucl.Phys.B 142 (1978) 29

- First observation of charmonium sequential suppression in heavy ion collisions at RHIC (3.5σ, 0-80%)
- Ratio decreases towards central collisions

Double ratio



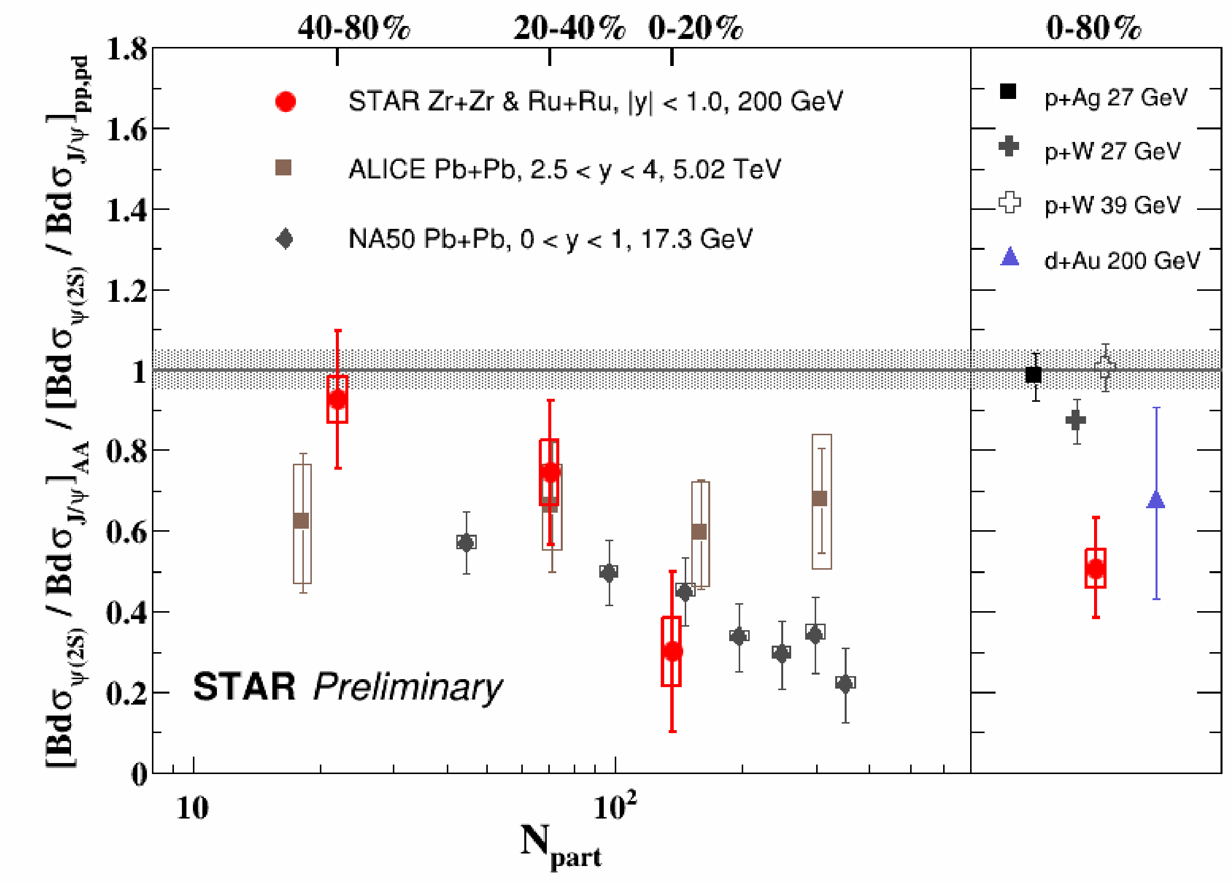
$$\frac{[(Bd\sigma_{\psi(2s)})/(Bd\sigma_{J/\psi})]_{AA}}{[(Bd\sigma_{\psi(2s)})/(Bd\sigma_{J/\psi})]_{pp,pd}}$$

pp reference is the average of measurements in p+p(d) by NA51, ISR and PHENIX

PHENIX, Phys.Rev.Lett. 111 (2013)
PHENIX, Phys.Rev.D, 85,092004 (2012)
NA50, Eur.Phys.J.C 48, (2006)
E772, Phys.Rev.Lett. 66 (1991) 133-136

- ψ(2S) over J/ψ double ratio is smaller than that in p+A collisions

Double ratio



$$\frac{[(Bd\sigma_{\psi(2s)})/(Bd\sigma_{J/\psi})]_{AA}}{[(Bd\sigma_{\psi(2s)})/(Bd\sigma_{J/\psi})]_{pp,pd}}$$

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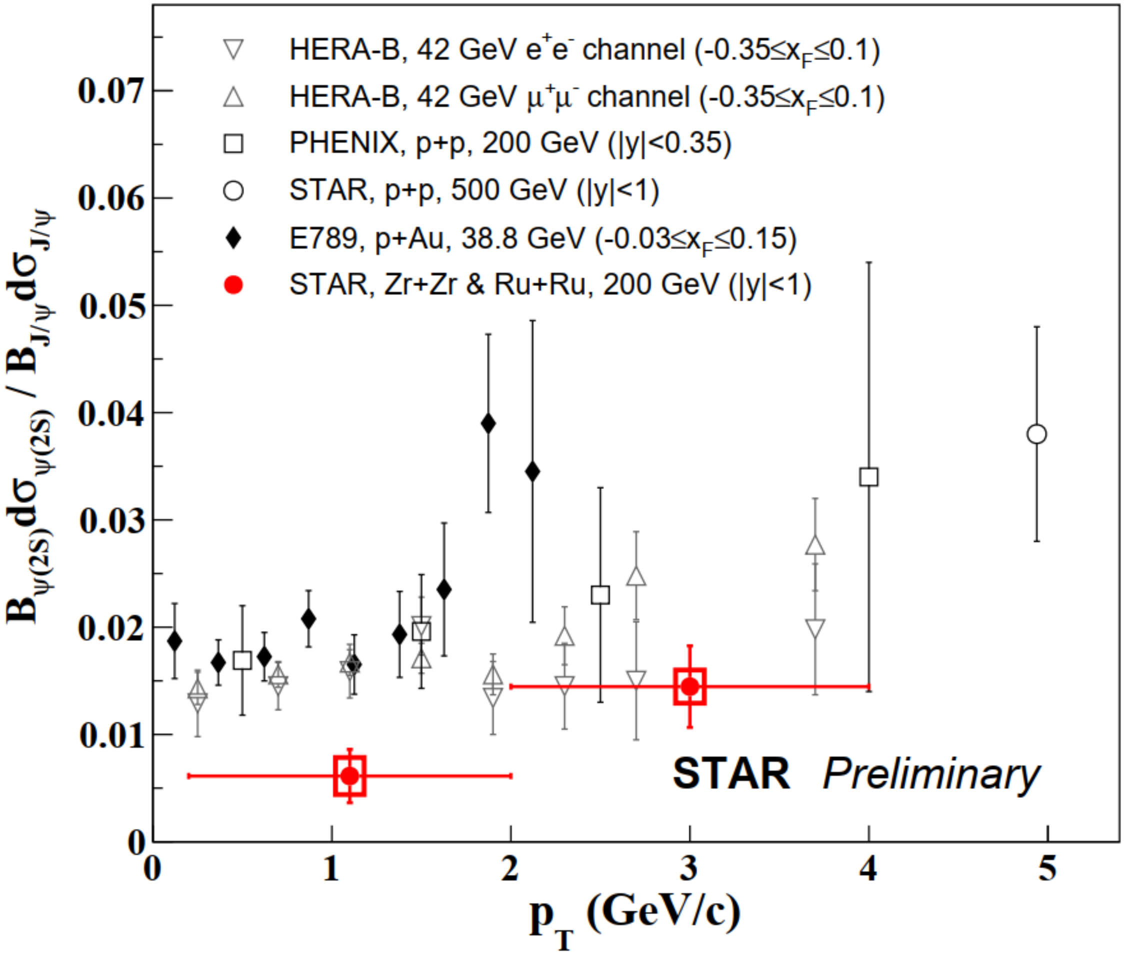
NA50, Eur.Phys.J.C 48, (2006)
E772, Phys.Rev.Lett. 66 (1991) 133-136

- ψ(2S) over J/ψ double ratio is smaller than that in p+A collisions
- Centrality dependence trend seems be more similar to that at SPS than at LHC

$\psi(2S)$ to J/ψ ratio vs p_T



- Increases with p_T in isobaric collisions
- Significantly lower than that in p+p and p+A collisions at $p_T < 2$ GeV/c
- Less conclusive at higher p_T due to large uncertainties in both p+p and A+A

STAR, Phys.Rev.D 100 (2019)
PHENIX, Phys.Rev.D, 85,092004 (2012)
HERA-B, Eur.Phys.J.C 49 (2007)
E789, Phys.Rev.D 52 (1995) 1307, 1995.

Summary

- Significant suppression of charmonium in central heavy-ion collisions
- First observation of sequential suppression for charmonium at RHIC
- No significant collision system size dependence of J/ψ R_{AA} for similar $\langle N_{part} \rangle$ at RHIC

Thank you!