



Measurement of J/ψ polarization and spin alignment in Ru+Ru and Zr+Zr collisions at $\sqrt{s_{NN}} = 200$ GeV at STAR

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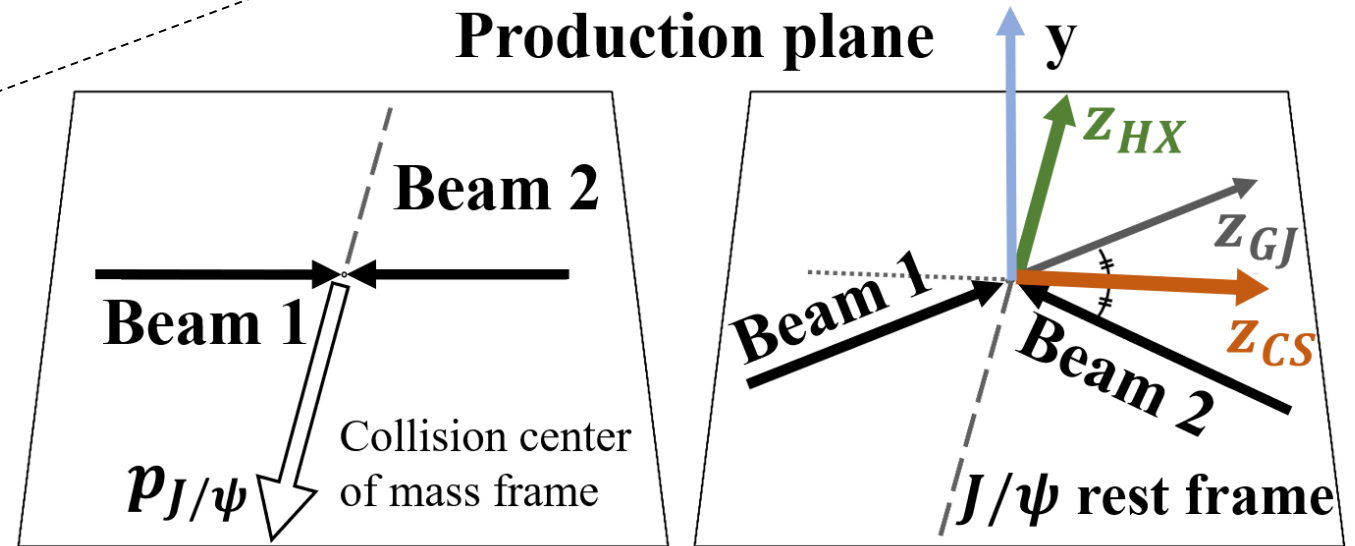
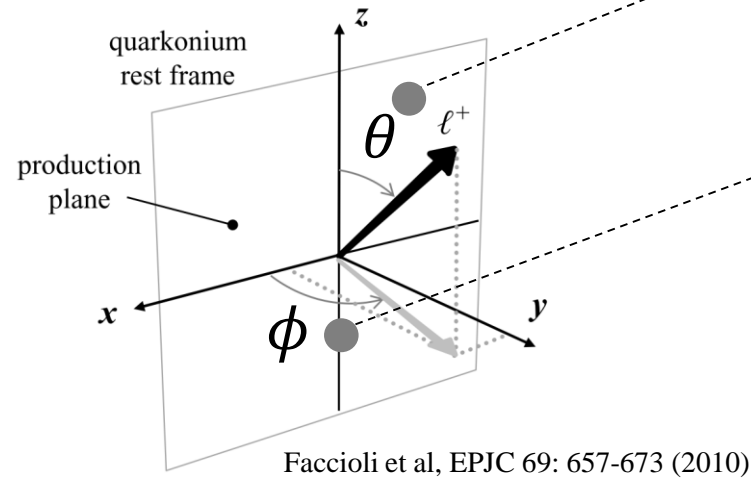
- Introduction and motivation
- J/ψ polarization in Helicity frame and Collins-Soper frame
- J/ψ global spin alignment
- Summary

J/ψ polarization



✓ Angular distribution of the decayed leptons:

$$W(\cos\theta, \phi) \propto 1 + \lambda_\theta \cos^2\theta + \lambda_\phi \sin^2\theta \cos 2\phi + \lambda_{\theta\phi} \sin 2\theta \cos\phi$$



➤ Definition of the z-axis:

Helicity frame (HX): J/ψ momentum direction

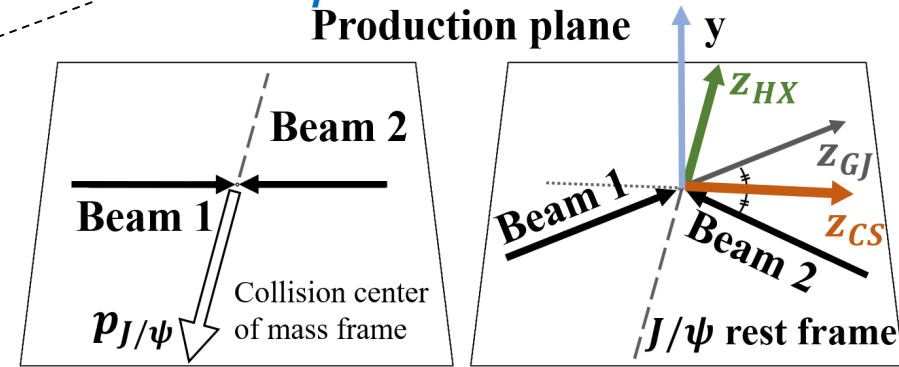
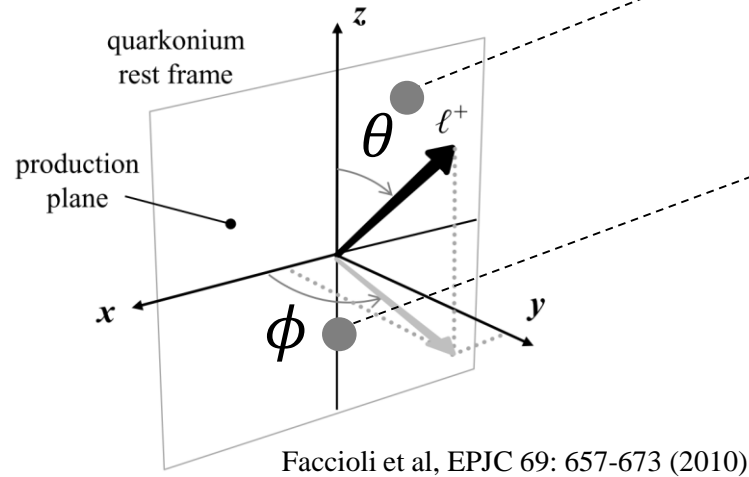
Collins-Soper frame (CS): bisector of angle between beams

J/ψ polarization



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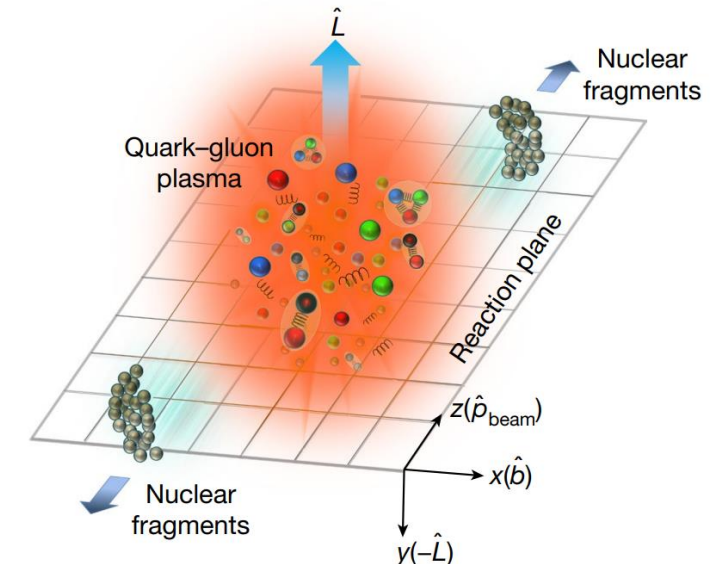


➤ Definition of the z-axis:

Helicity frame (HX): J/ψ momentum direction

Collins-Soper frame (CS): bisector of angle between beams

Event plane: axis orthogonal to reaction plane

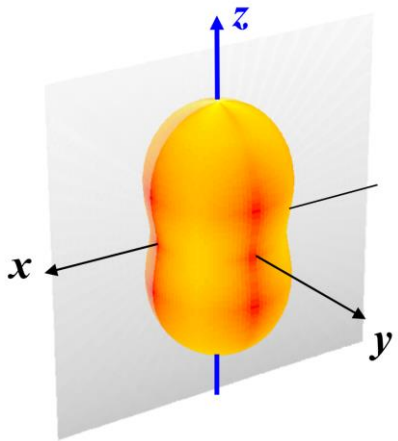


J/ψ polarization



✓ Angular distribution of the decayed leptons:

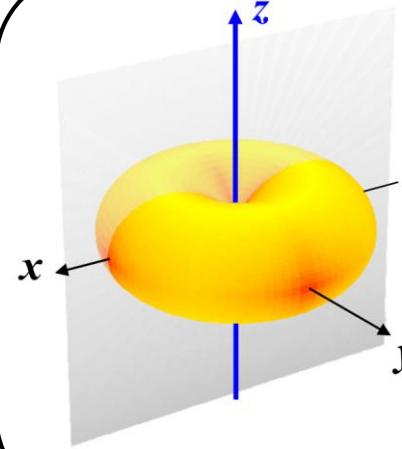
$$W(\cos\theta, \phi) \propto 1 + \lambda_\theta \cos^2 \theta + \lambda_\phi \sin^2 \theta \cos 2\phi + \lambda_{\theta\phi} \sin 2\theta \cos \phi$$



$$\frac{dN}{d\Omega} \propto 1 + \cos^2 \theta$$

Transverse polarization

$$|J/\psi\rangle = |1, +1\rangle \text{ or } |1, -1\rangle$$



$$\frac{dN}{d\Omega} \propto 1 - \cos^2 \theta$$

Longitudinal polarization

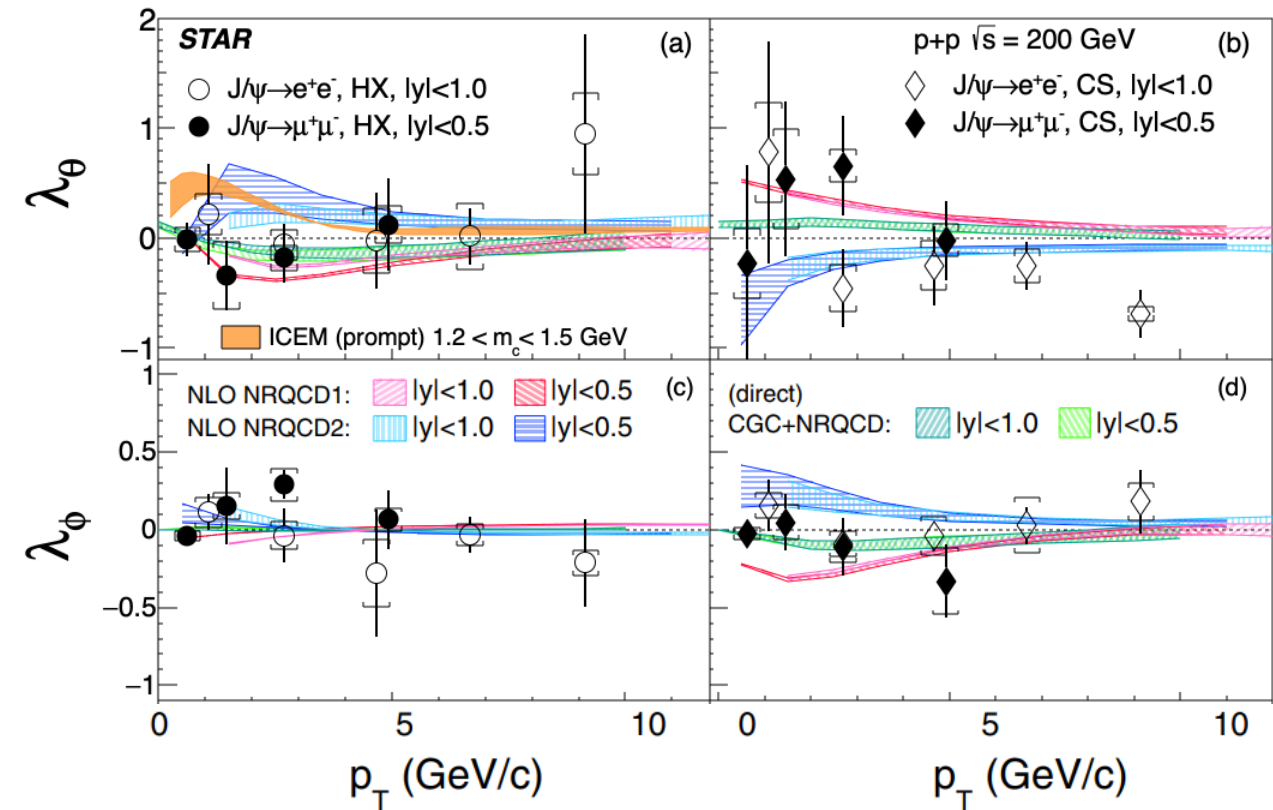
$$|J/\psi\rangle = |1, 0\rangle$$

Faccioli et al, EPJC 69: 657–67 (2010)

Motivation: pp collisions



- J/ψ polarization can be used to study production mechanism in pp collisions
 - colour-singlet vs colour-octet vs gluon fragmentation Faccioli et al, EPJC 69: 657–67 (2010)
- Feed down also plays a role
 - Prompt J/ψ = **Direct**^{60%} + **feed down**^{40%}
 - Non-prompt: b-hadron decay



STAR PRD 102, 092009 (2020)

- No sizeable polarization for inclusive J/ψ in pp collisions at $\sqrt{s} = 200$ GeV

Could the inclusive J/ψ polarization be different in heavy-ion collisions?

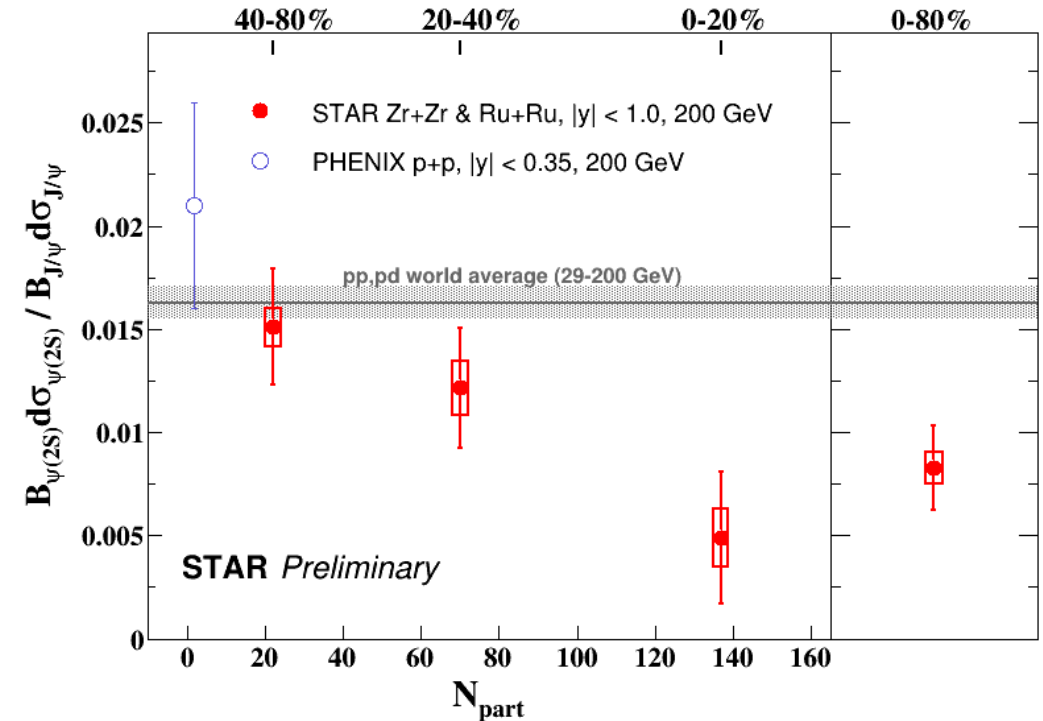
Motivation: heavy-ion collisions



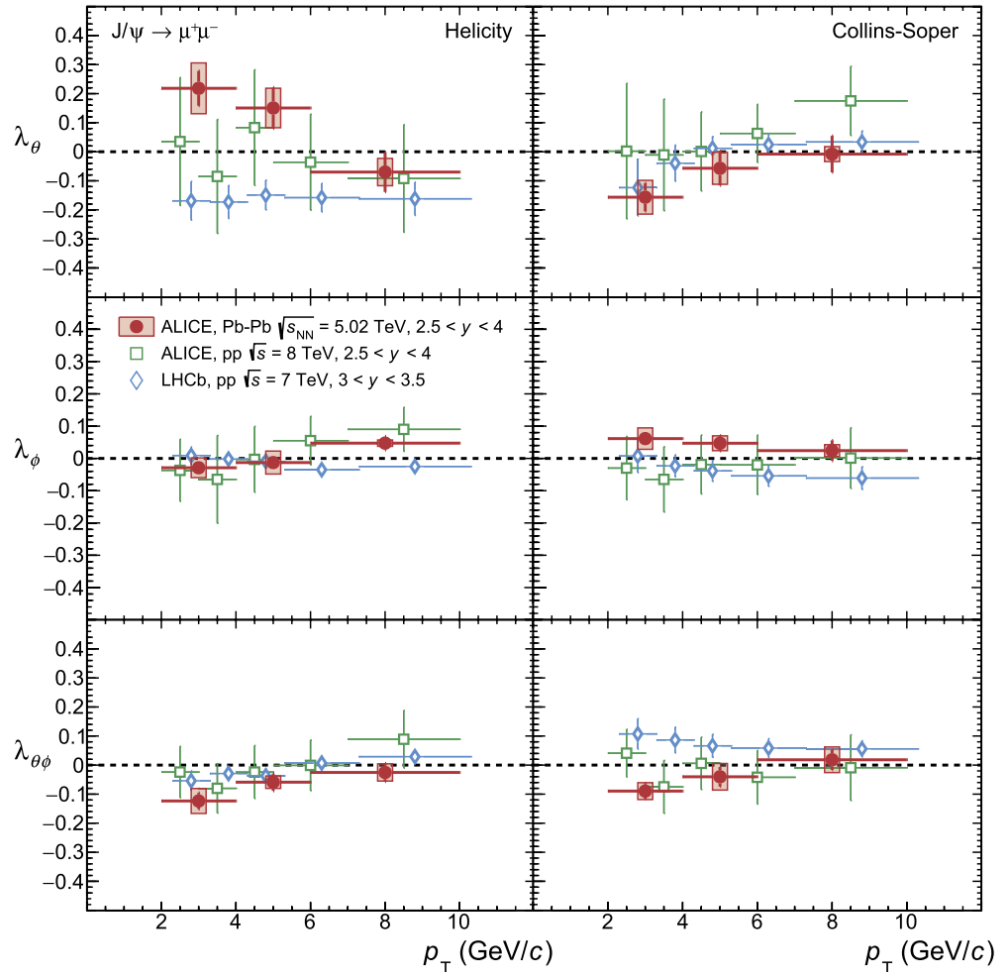
- QGP affects the polarization of J/ψ ?

“Theoretical prediction: J/ψ polarization at small p_T , and find that it translates into the asymmetry of the $e^+e^- (\mu^+\mu^-)$ angular distribution $W(\theta) = 1 + \lambda_\theta \cos^2 \theta$, with $\lambda_\theta \cong 0.35 - 0.4$.”

B. L. Ioffe and D. E. Kharzeev, PRC 68, 061902(R) (2003)



- Modification of J/ψ feed-down fractions due to larger $\psi(2s)$ and χ_c suppression in the QGP



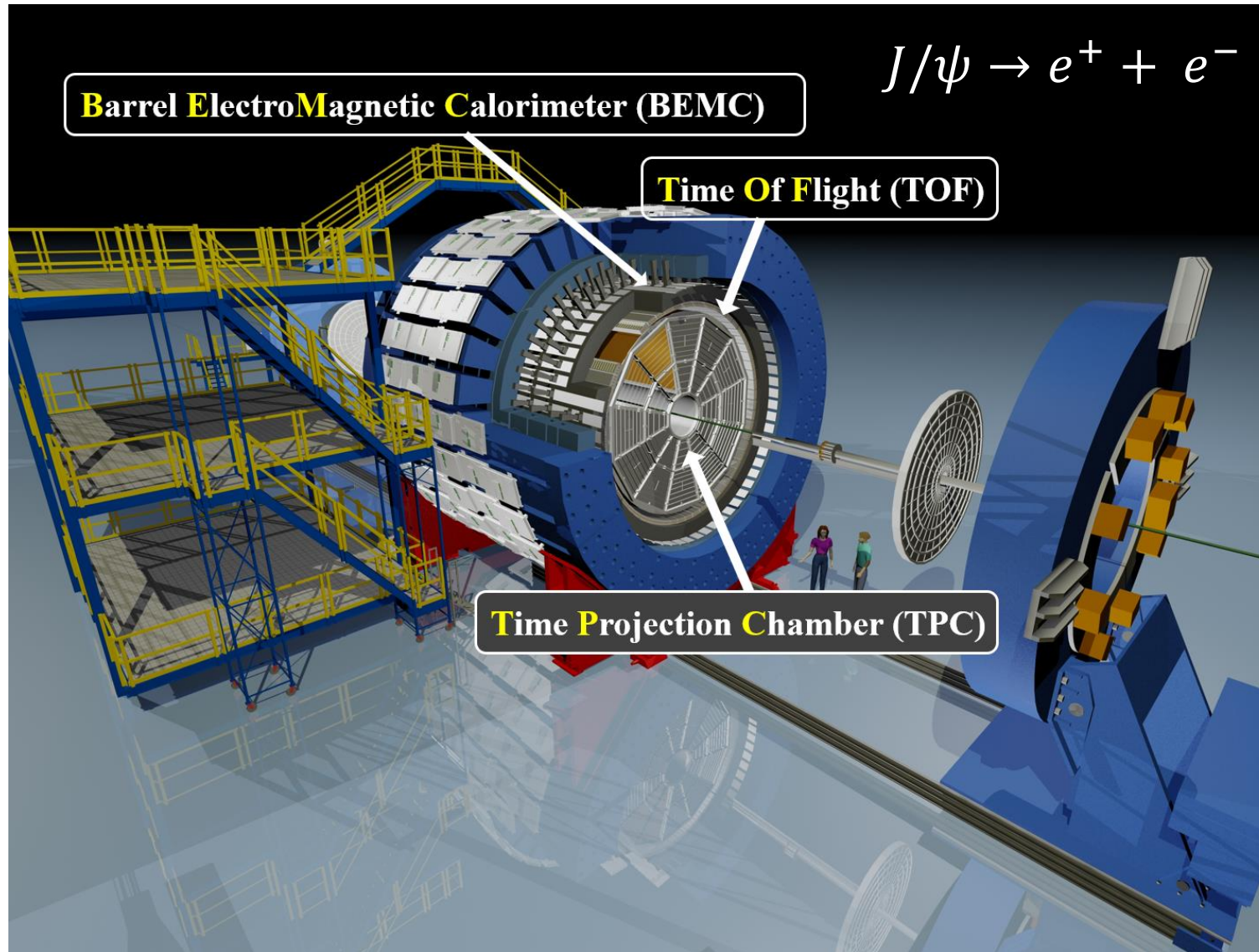
ALICE PLB 815 136146 (2021)

- Hint of non-zero J/ψ polarization at LHC
 - λ_θ shows a 2σ deviation w.r.t zero in HX for $2 < p_T < 4$ GeV/c
 - Regenerated J/ψ is expected to have zero polarization \Longrightarrow dilute polarization signal

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- Is J/ψ polarize at the **RHIC energy**?
 - Smaller regeneration contribution
 - Different rapidity range
 - ...

The Solenoid Tracker At RHIC (STAR)



➤ TPC: $-1 < \eta < 1$

Tracking, momentum
and energy loss

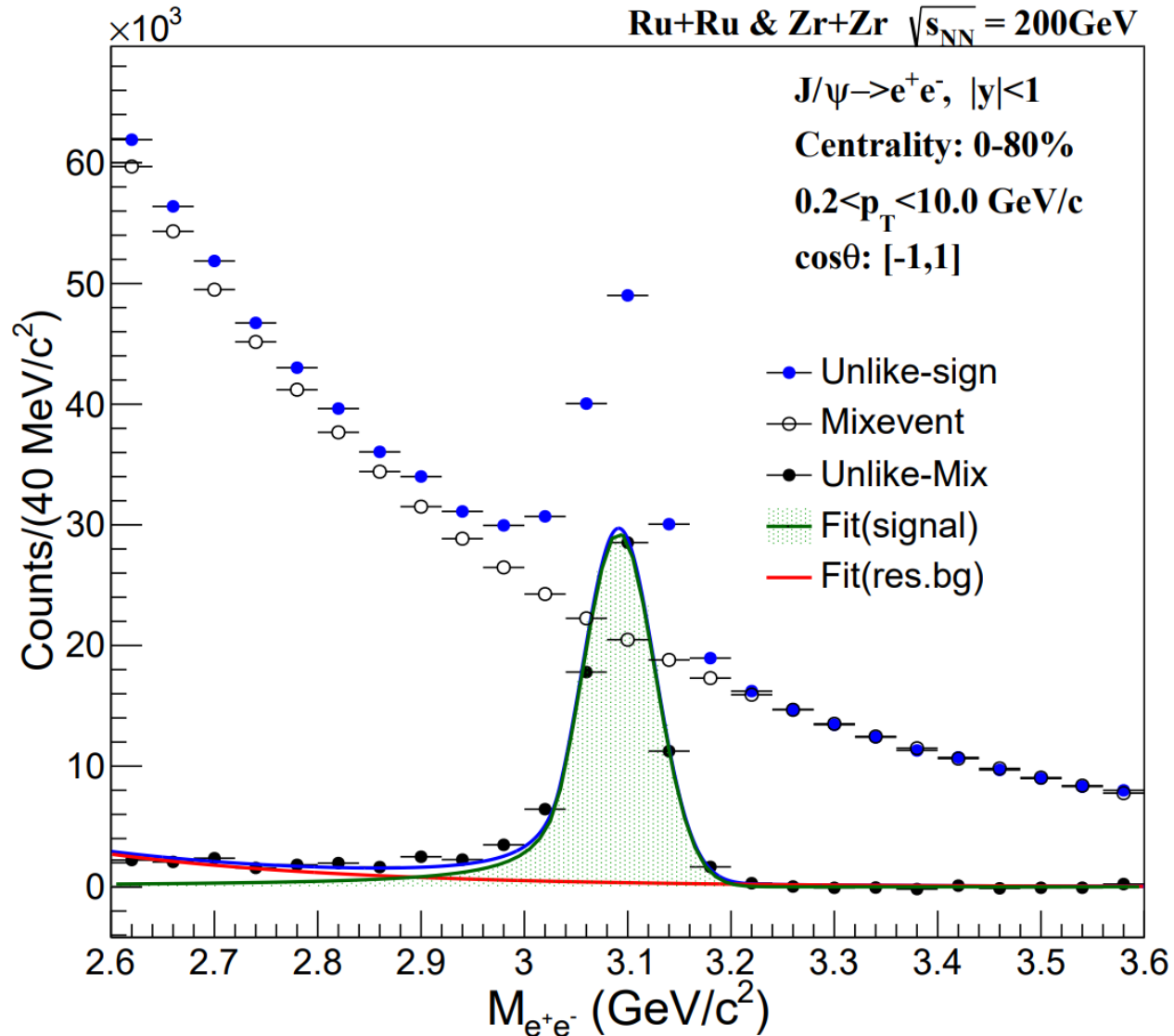
➤ TOF: $-1 < \eta < 1$

Time of flight, particle
identification

➤ BEMC: $-1 < \eta < 1$

Identification of
high- p_T electrons

Analysis procedure: signal extraction



1. Signal extraction

- Decay channel : $J/\psi \rightarrow e^+e^-$, $|y| < 1$
- Combinatorial background: mixed-event technique
- Residual background: an exponential function
- J/ψ yields extracted as a function of $\cos\theta$ and ϕ separately

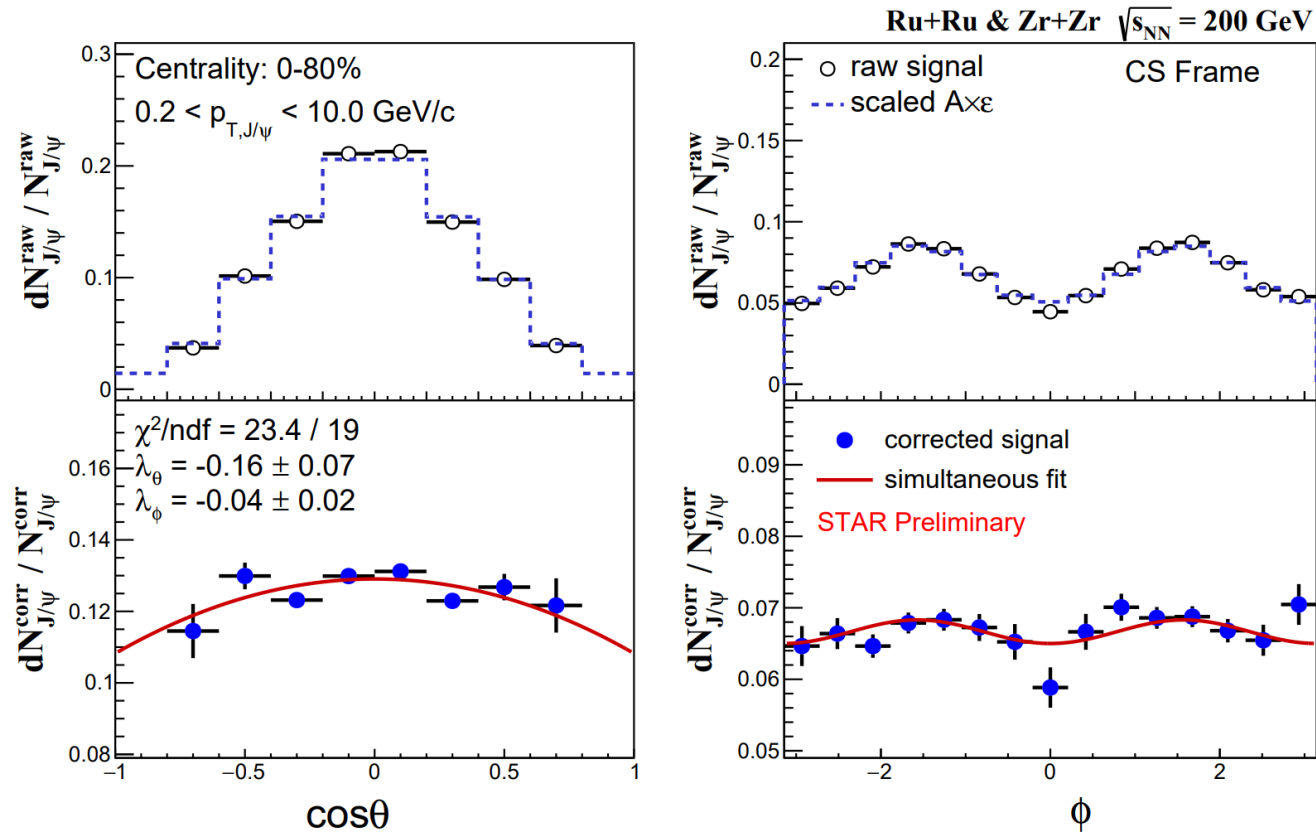
Analysis procedure: extract polarization



2. Acceptance \times efficiency correction

- **Iterative procedure:** tuning of J/ψ polarization in simulation according to data

3. Polarization parameters extraction: simultaneously fit the corrected yield distributions

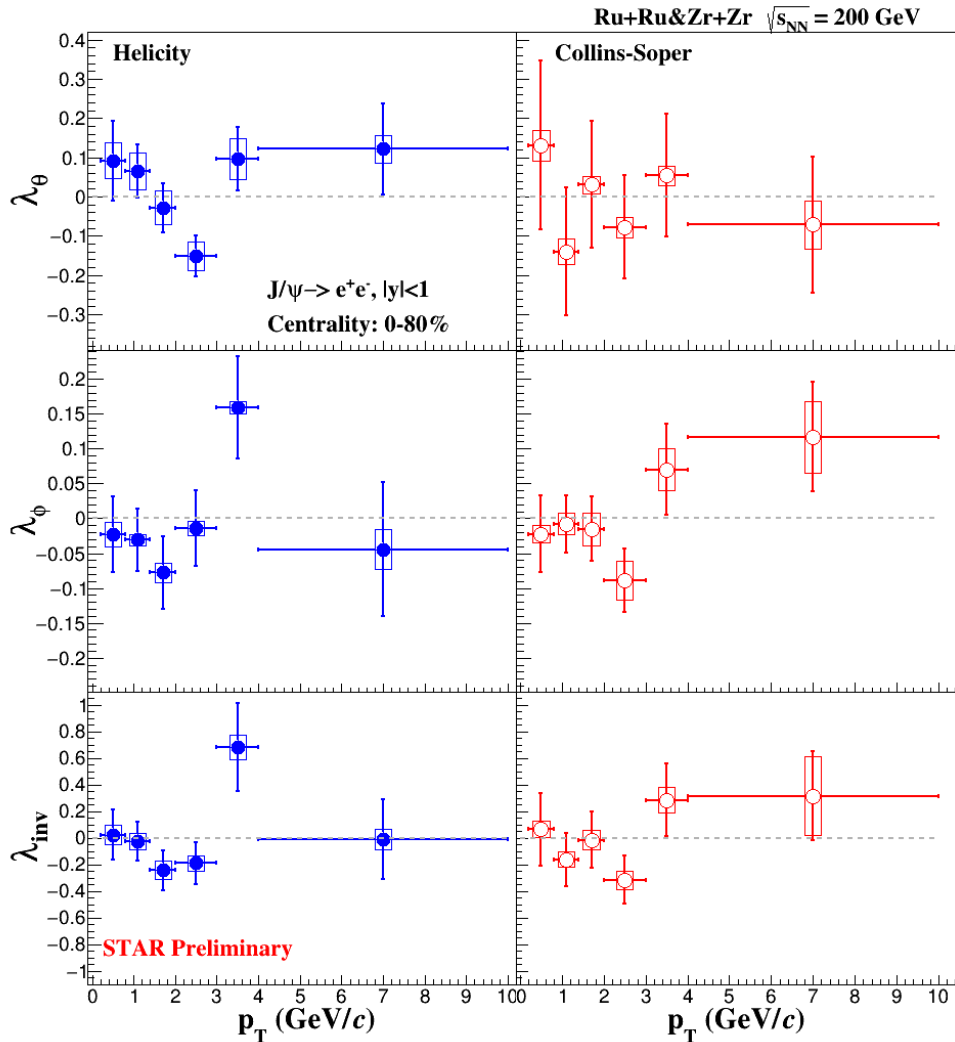


➤ **Simultaneously fit** angular distribution and extract polarization parameters

$$W(\theta) = 3 \times \frac{1 + \lambda_\theta \cos^2 \theta}{2 \times (3 + \lambda_\theta)}$$

$$W(\phi) = \frac{2 \times \lambda_\phi}{(3 + \lambda_\theta) \times 2\pi} \cos 2\phi$$

Transverse momentum dependence



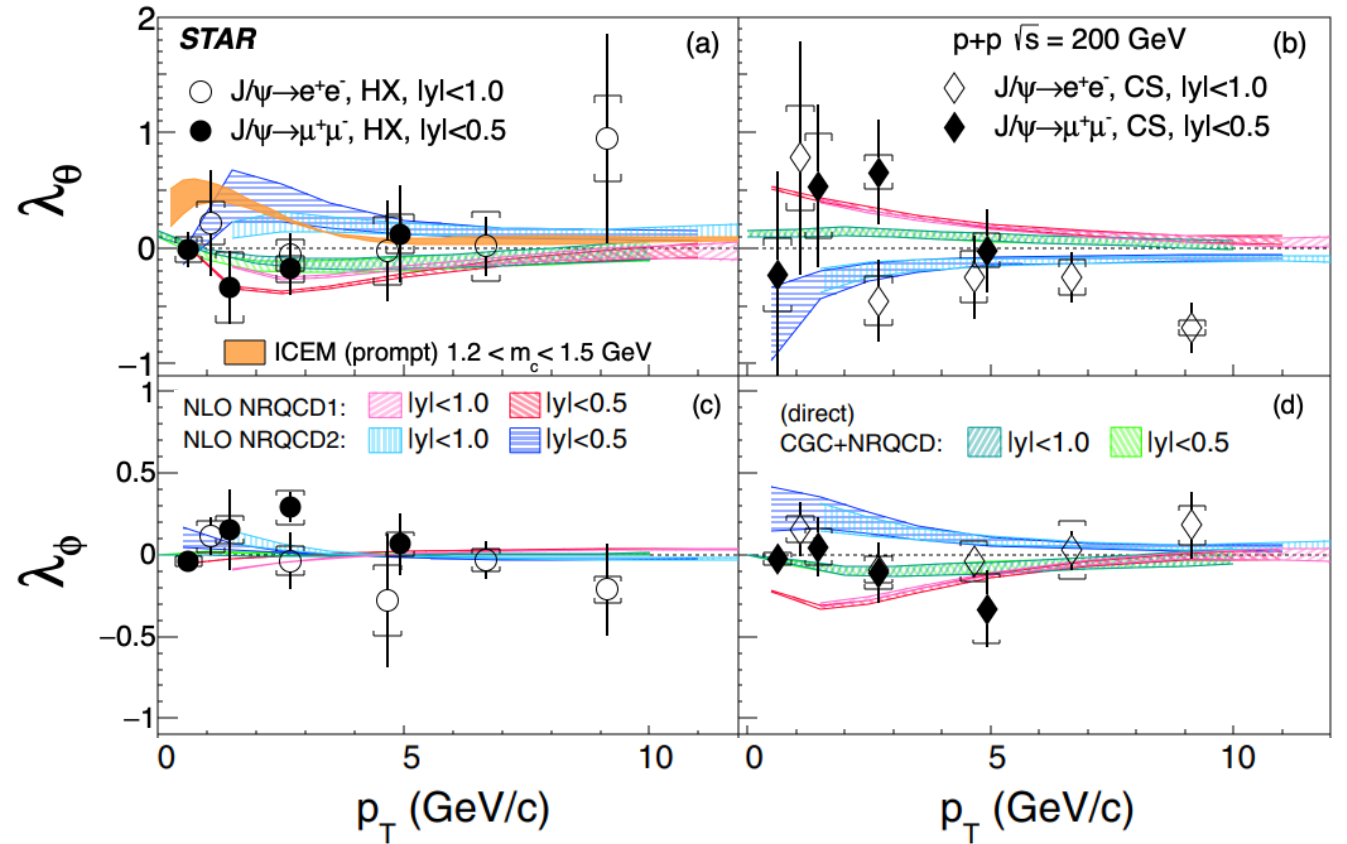
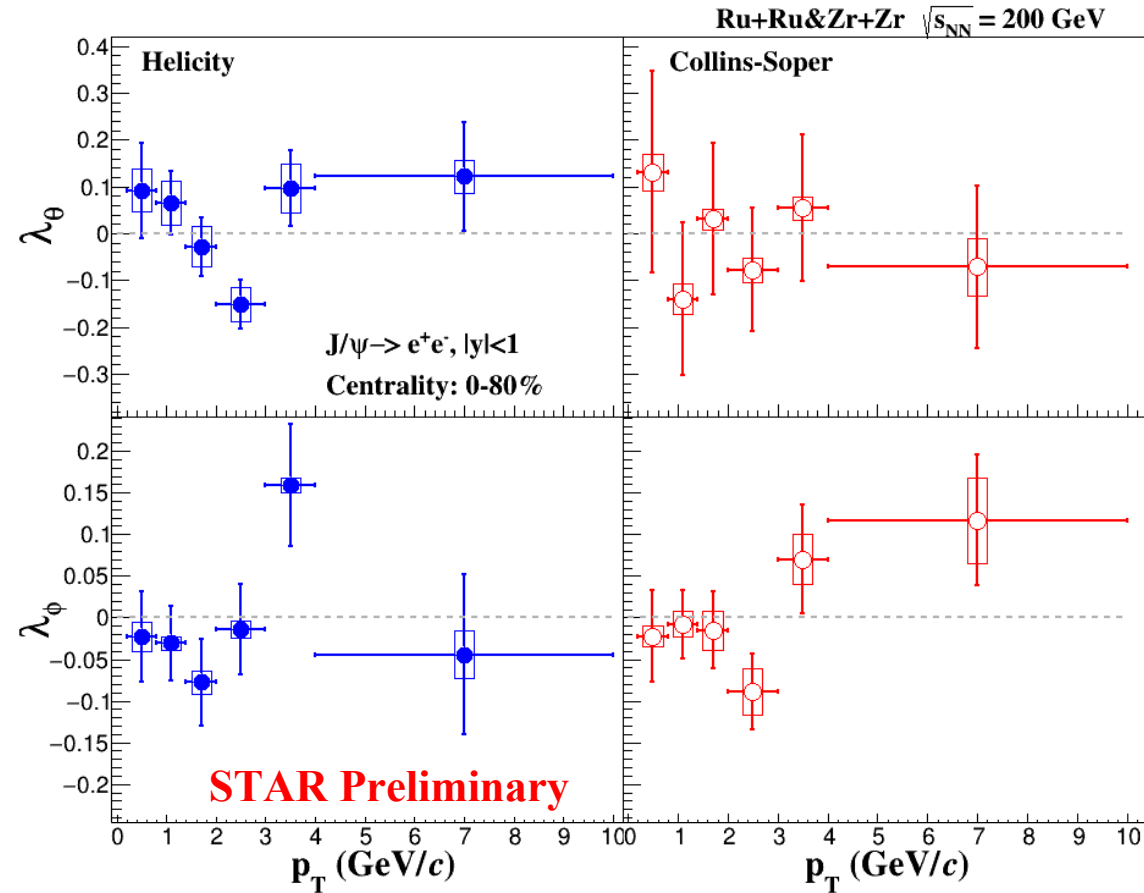
➤ J/ψ polarization vs p_T :

- $\lambda_\theta, \lambda_\phi$ are consistent with zero in HX and CS frames
- **Hint of a non-trivial p_T dependence** in the HX frame but overall no significant p_T dependence in either HX and CS

➤ Frame invariant quantity $\lambda_{inv} = \frac{\lambda_\theta + 3\lambda_\phi}{1 - \lambda_\phi}$

➤ λ_{inv} are consistent between HX and CS frames

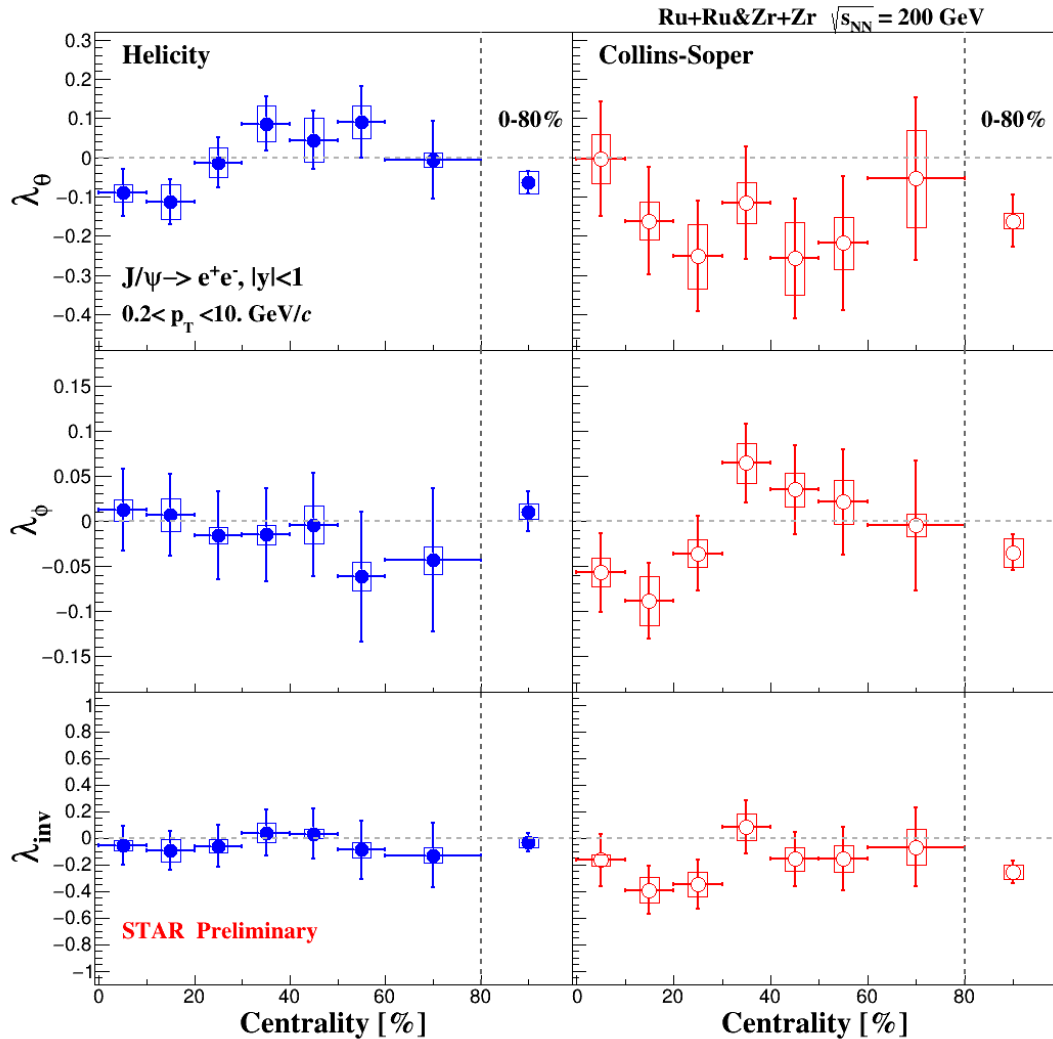
J/ ψ polarization: Isobar vs pp



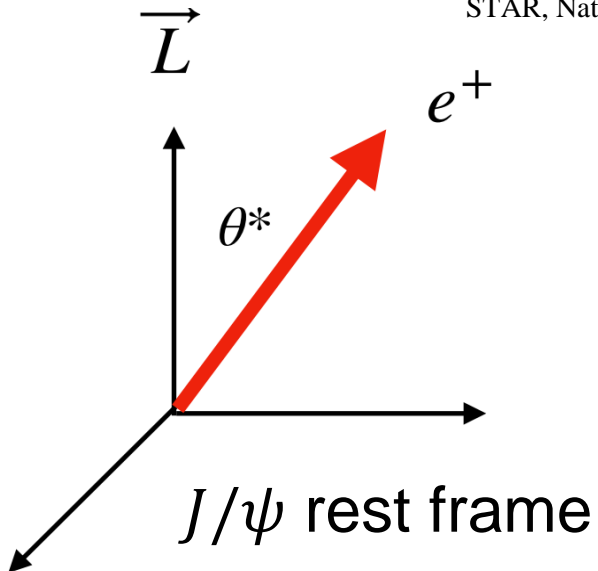
STAR PRD 102, 092009 (2020)

➤ λ_θ and λ_ϕ in isobar and pp collisions are consistent with zero within uncertainties

Centrality dependence



- No significant dependence of λ_θ , λ_ϕ from central to peripheral event
- λ_{inv} are consistent between HX and CS frames

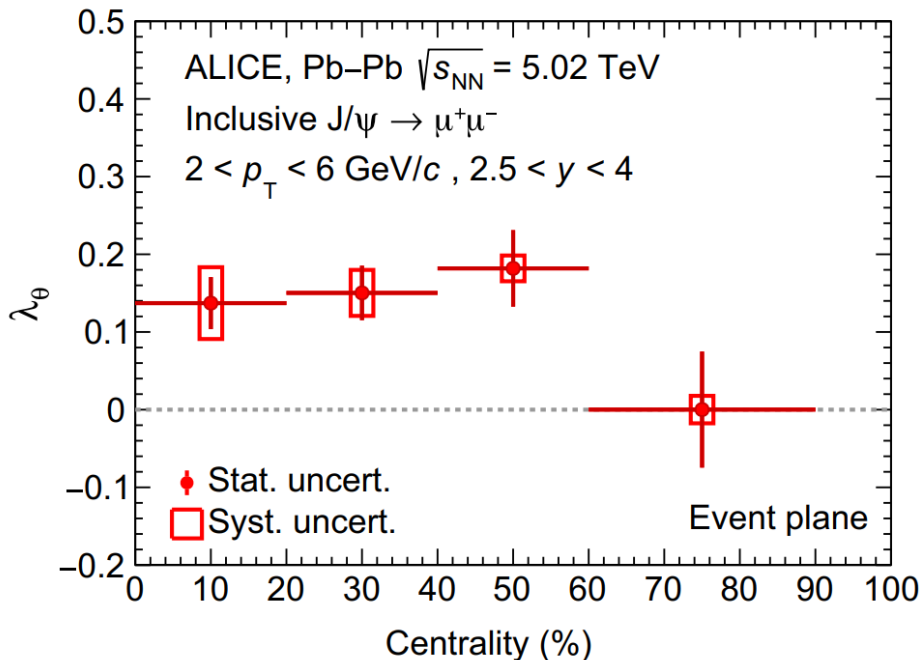


$\rho_{00} \neq 1/3 \rightarrow$ spin alignment

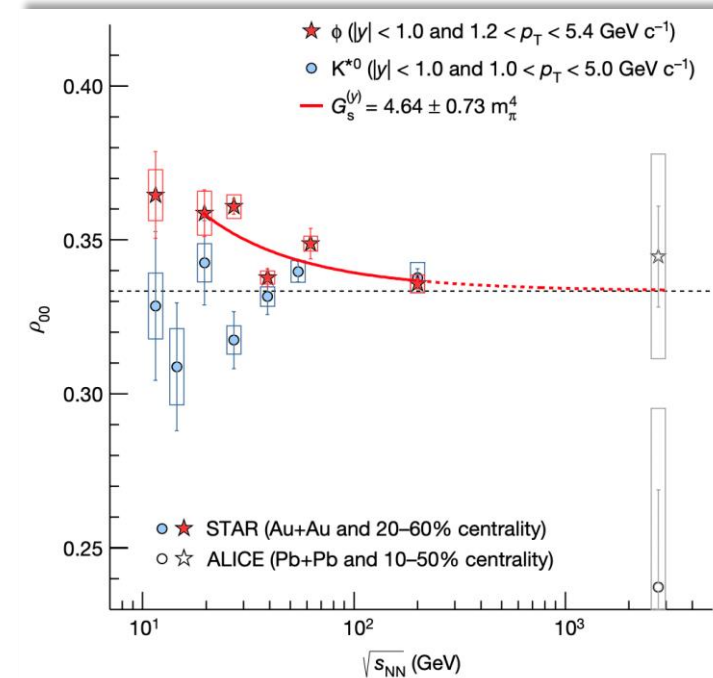
J/ ψ global spin alignment



- ϕ meson $\rho_{00} > 1/3$ at RHIC
- Might be caused by strange quark strong force field
- Similar effect expected for regenerated J/ ψ



Alice PRL 131 4, 042303 (2023)



STAR, Nature 614, 244-248 (2023)

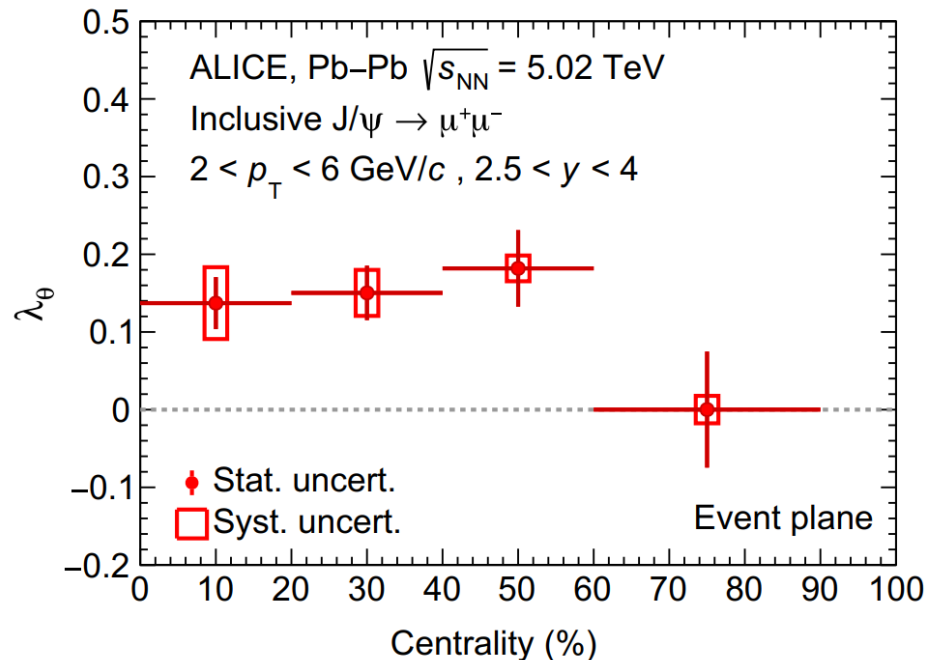
- J/ ψ $\rho_{00} < 1/3$ at LHC forward rapidity
 - Spin alignment signal up to 60% centrality
- Consistent with regeneration of polarized charm quarks
 - Spin-orbital momentum coupling

Z.-T. Liang and X.-N. Wang,
PLB 629, 20 (2005)

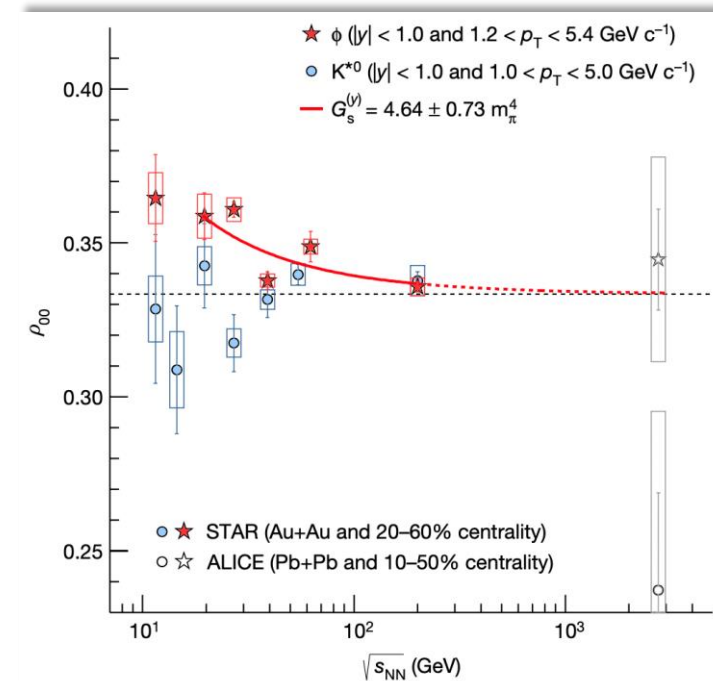
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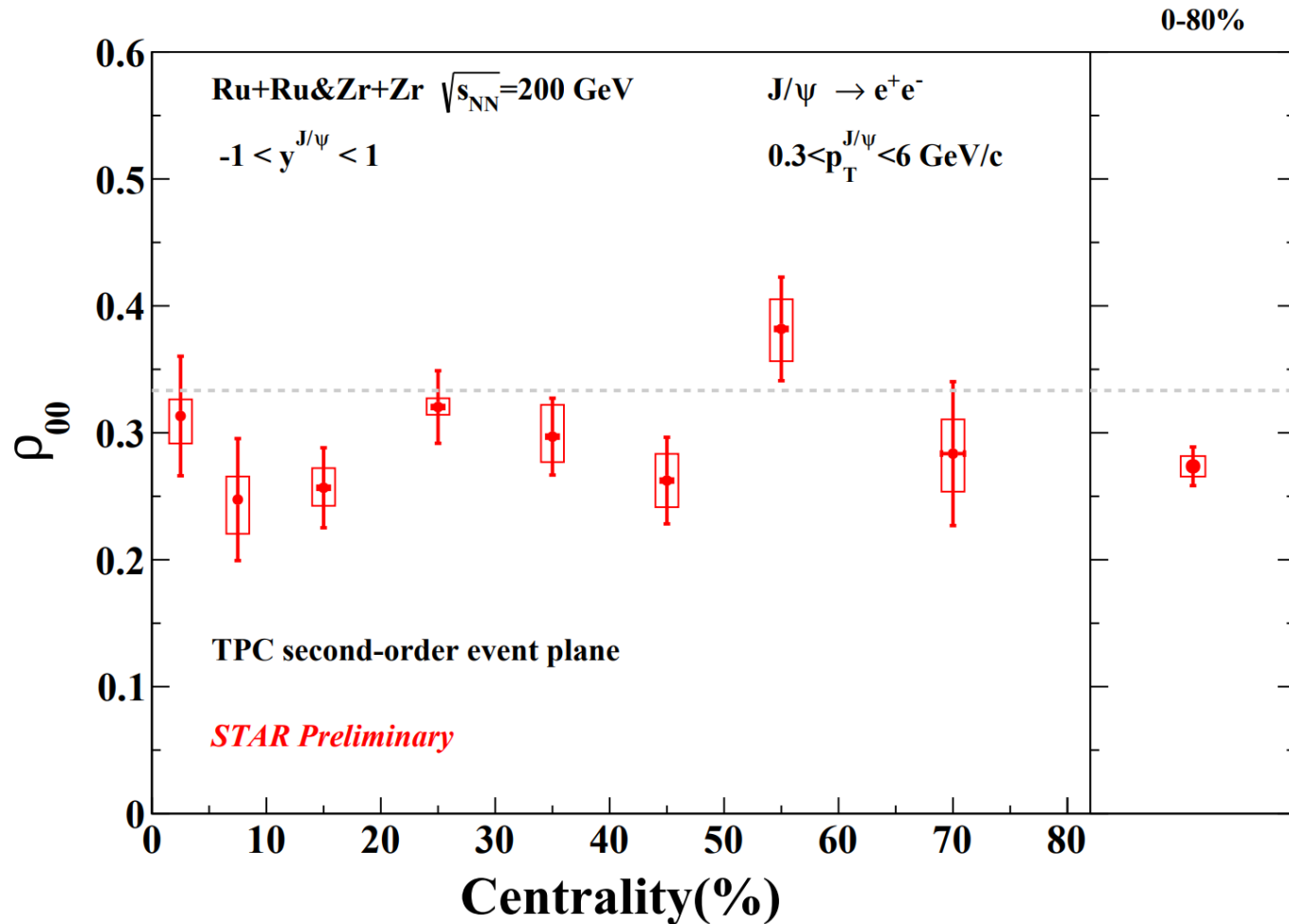


STAR, Nature 614, 244-248 (2023)

How about J/ψ spin alignment at RHIC energy?

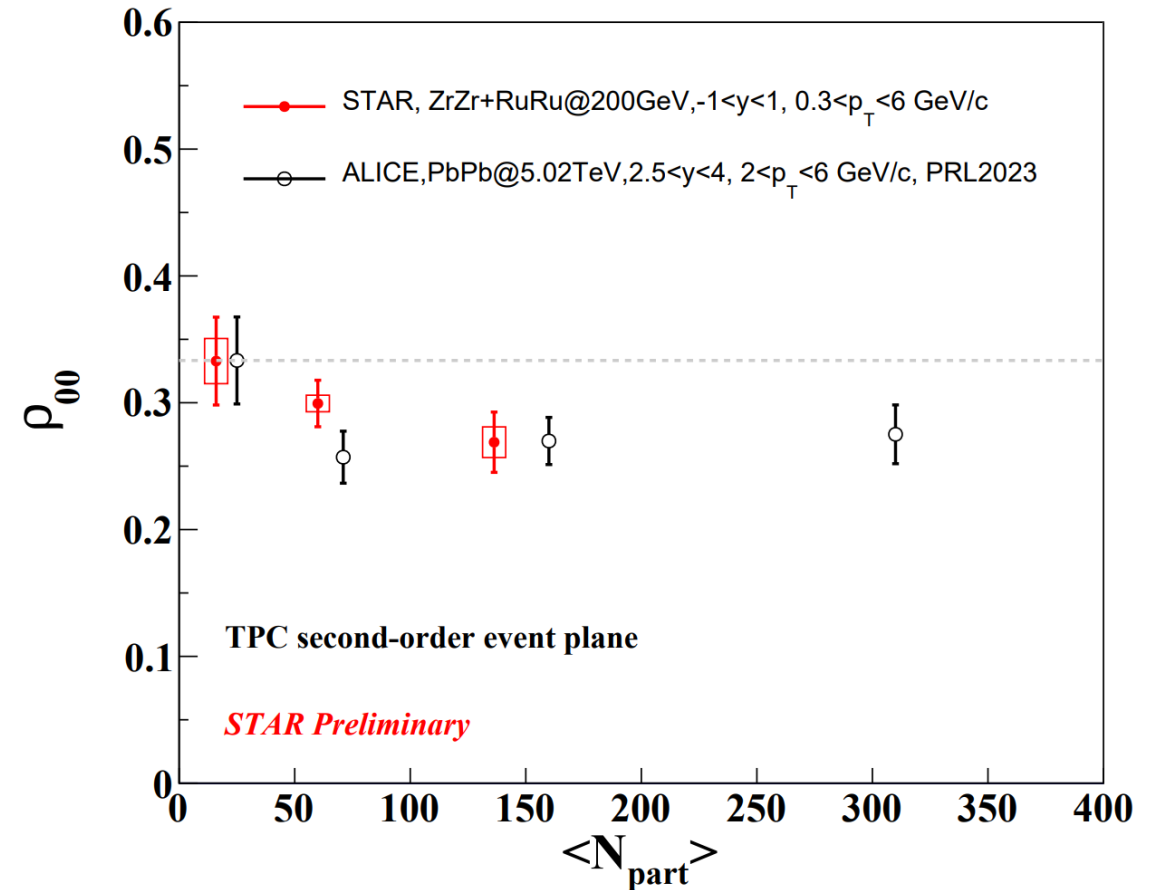
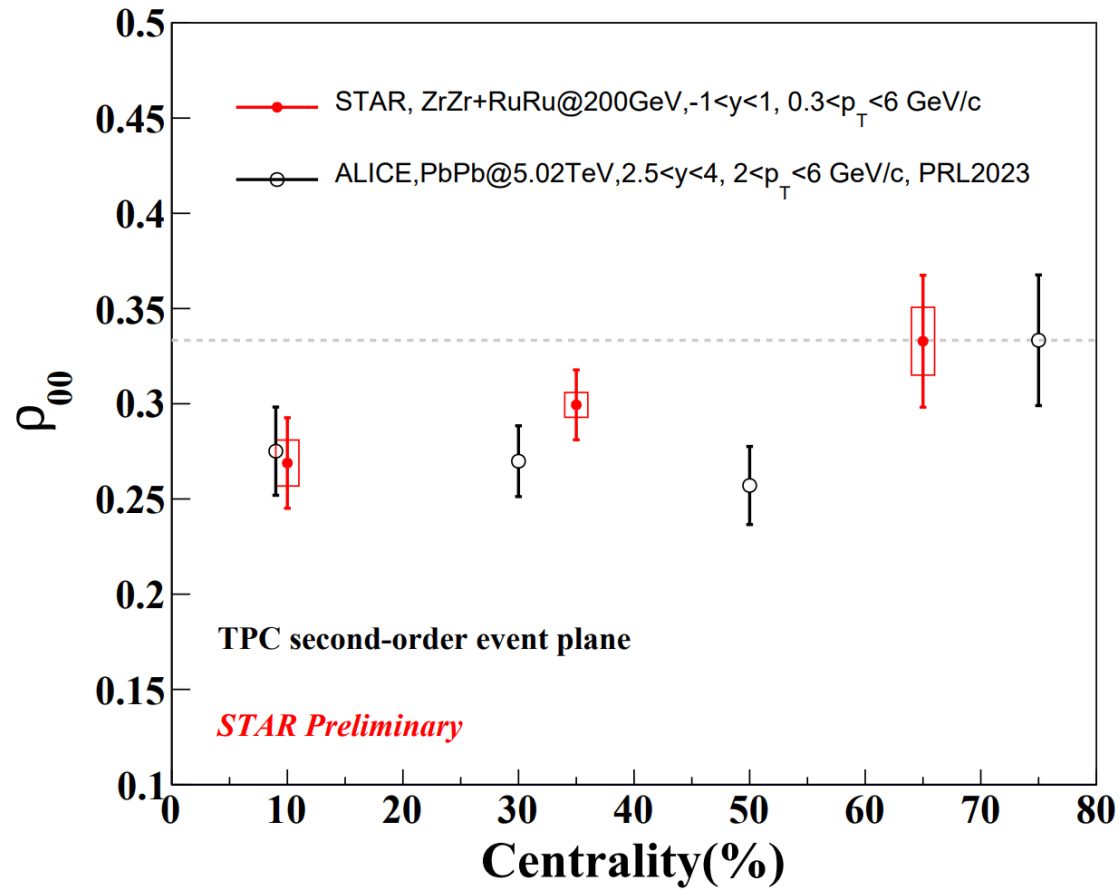
- Smaller regeneration than LHC

J/ψ global spin alignment: centrality dependence



- First measurement of ρ_{00} using second-order event plane at RHIC
- ρ_{00} lower than $1/3$ with a **significance of 3.5σ** for p_T from 0.3 to 6 GeV/c and 0-80% centrality
- No significant centrality dependence within uncertainty.

J/ψ global spin alignment: RHIC vs LHC



- The ρ_{00} at RHIC energy is comparable to LHC results, despite of very different collision energy, systems and rapidity

First measurement of J/ψ polarization and spin alignment with respect to TPC event-plane in heavy-ion collisions at RHIC

➤ J/ψ polarization

- $\lambda_\theta, \lambda_\phi$ consistent with zero in HX and CS frames
- No significant centrality and p_T dependence

➤ J/ψ global spin alignment

- ρ_{00} lower than 1/3 with a **significance of 3.5σ** for p_T from 0.3 to 6 GeV/c and 0-80% centrality
- Similar ρ_{00} values at RHIC and LHC, despite of very different collision energies, systems and rapidity

First measurement of J/ψ polarization and spin alignment with respect to TPC event-plane in heavy-ion collisions at RHIC

Thanks for your attention

➤ J/ψ polarization

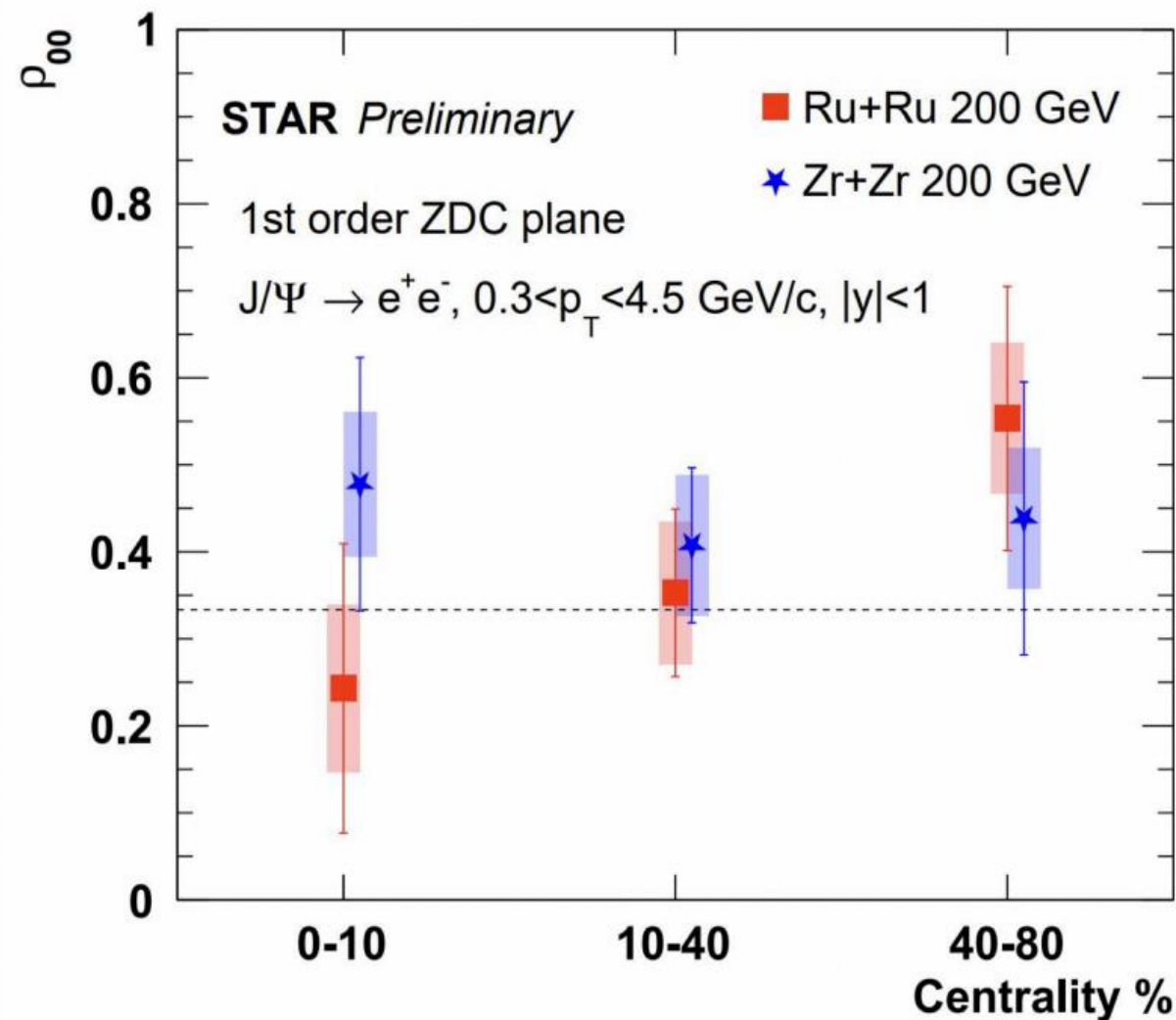
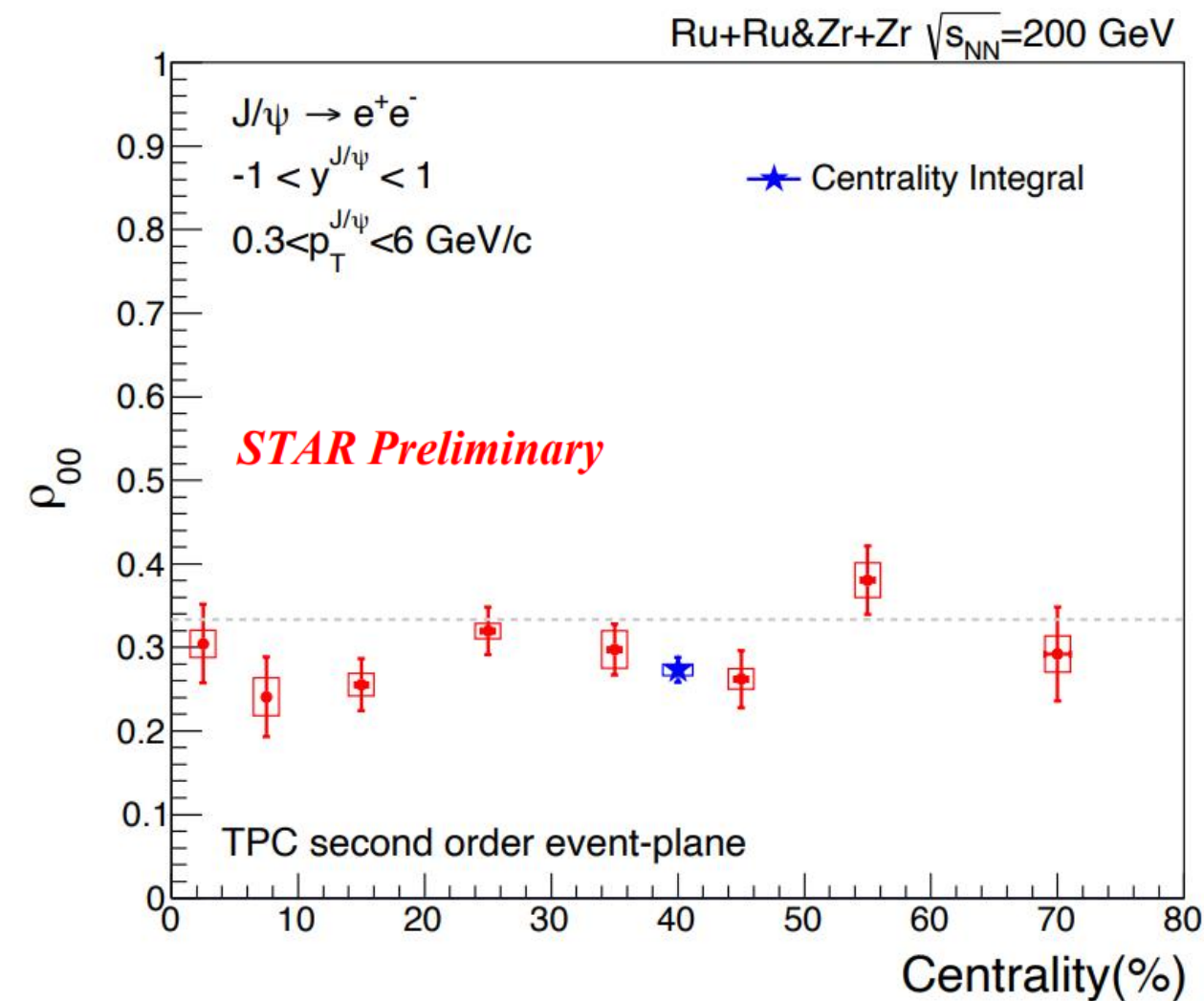
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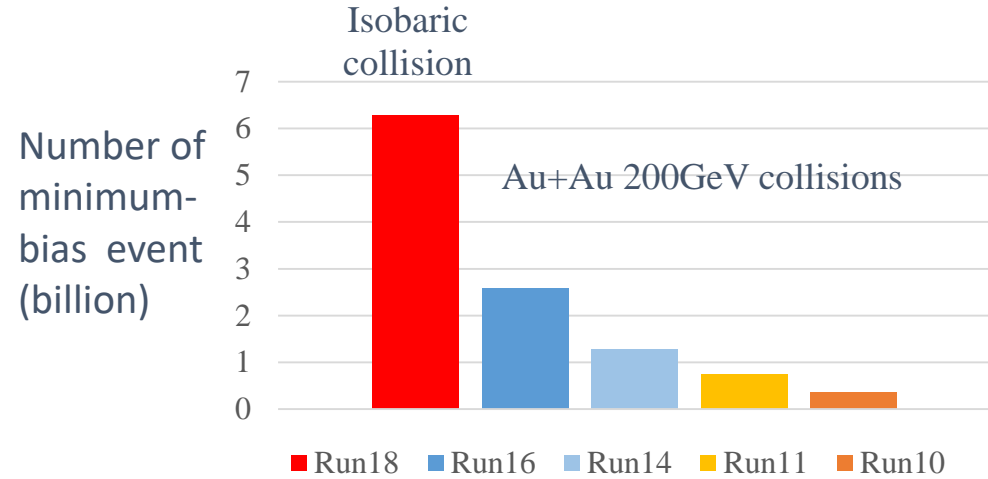
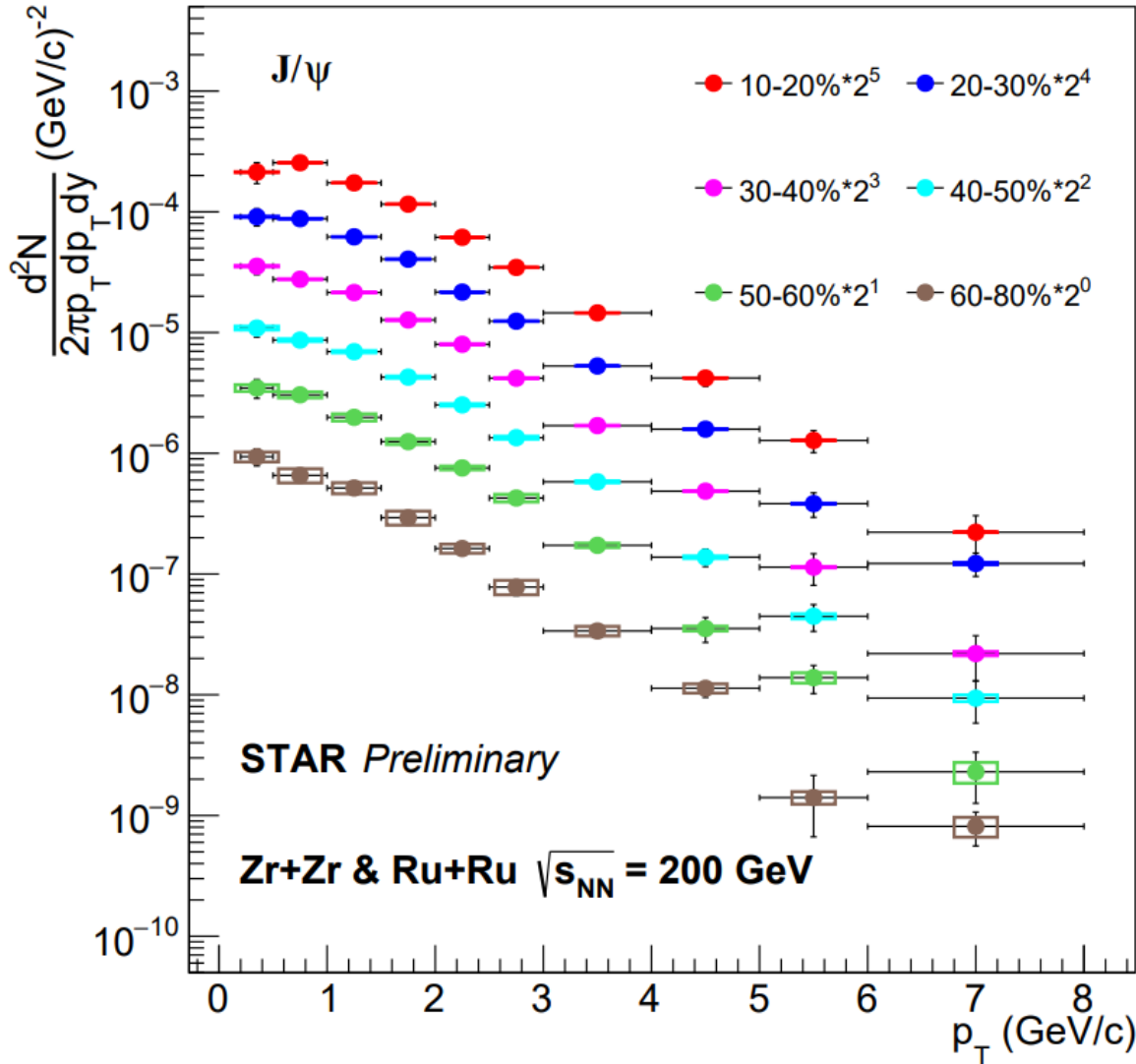
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Back up

ρ_{00}^{obs} vs centrality



p_T spectrum



Credit: Wangmei Zha

➤ Data sample: (Isobar data)

Ru+Ru & Zr+Zr collisions at $\sqrt{s_{NN}} = 200$ GeV

➤ **Isobar data** is the most accurate and highest statistical measurement of RHIC

Random event-plane

