



April 24 -28

极端核物质前沿研讨会

Workshop on extreme nuclear matter frontiers



Studies of J/ψ production and its dynamics in hadronic and nuclear collisions

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arXiv:2604.07005

PRD:113,054038 (2026)

PRL:136,122302 (2026)

J/ψ production study at 1980s

In 1974 November

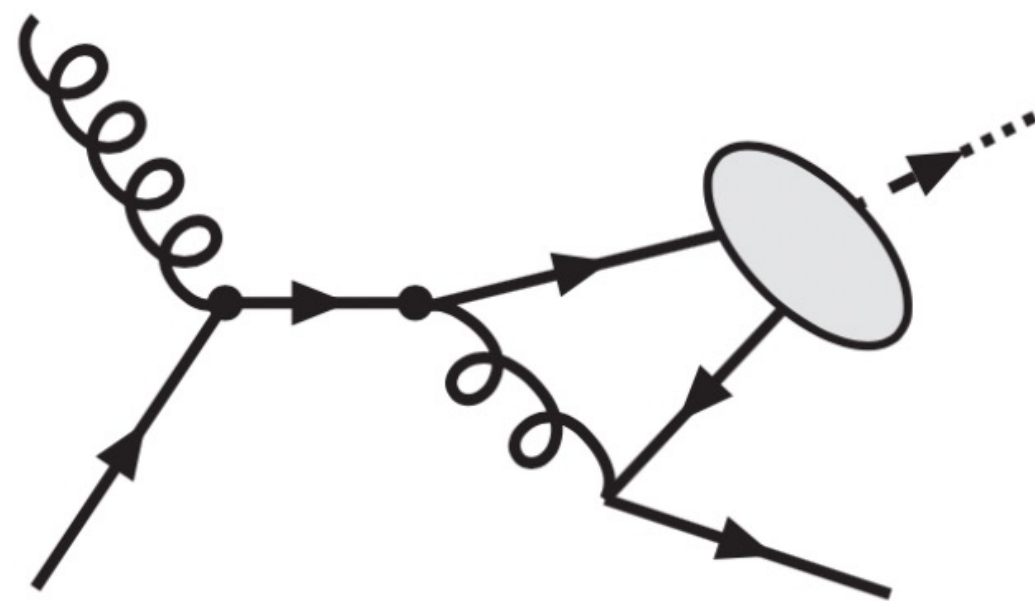
$$p + Be \rightarrow e^+ e^- + \text{anything}$$

$$e^- + e^+ \rightarrow \text{hadrons}$$

➤ The large mass of 3097 MeV/c² → charm quark

A non-relativistic approach in $c\bar{c}$ system (analogous to positronium)

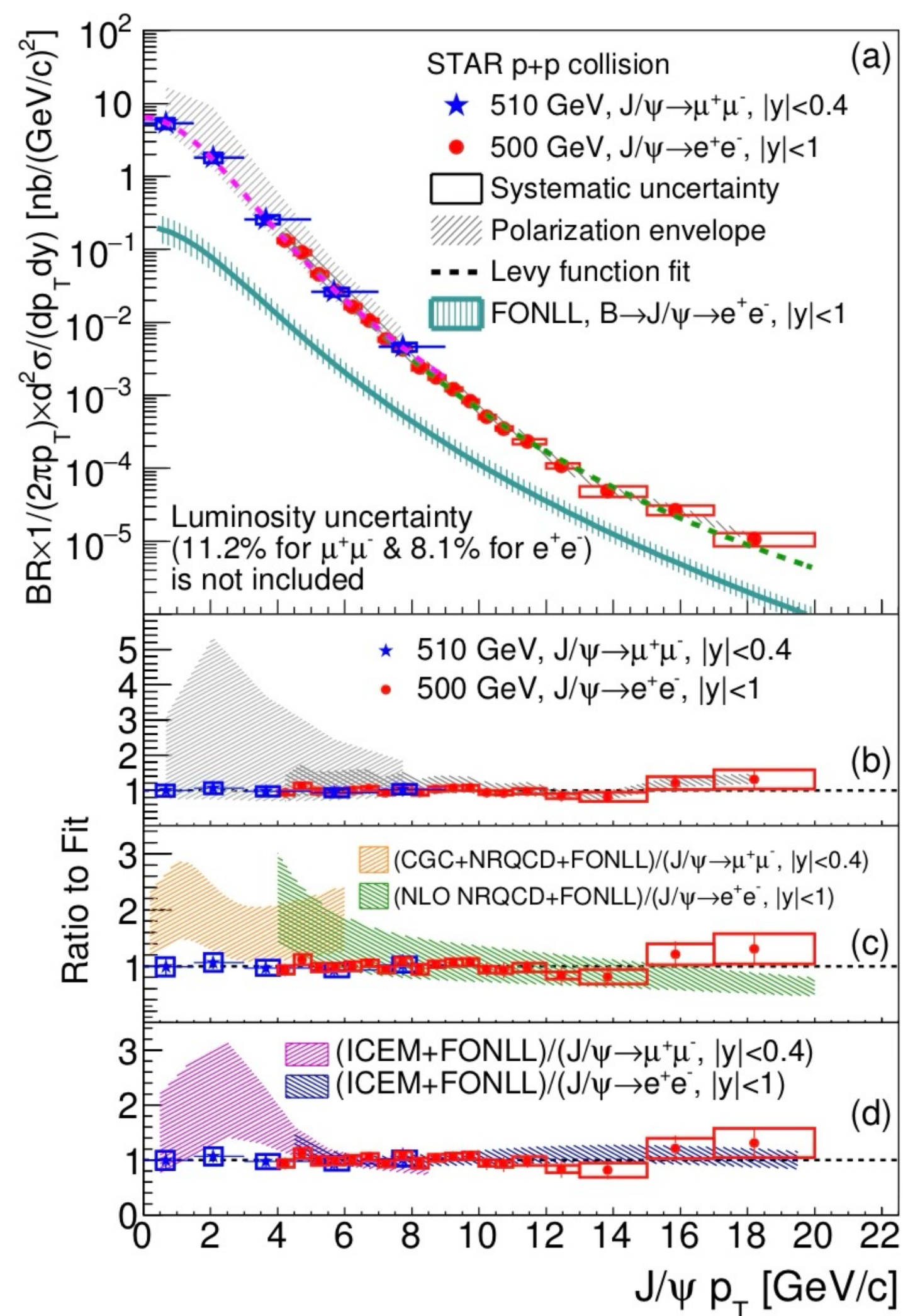
How the J/ψ is produced in details?



Color-singlet:

the produced $c\bar{c}$ ($^3S_1^{[1]}$) has the same quantum number as the final state J/ψ

J/ψ production mechanism study



➤ J/ψ production: “c \bar{c} pair + evolution” intuitive picture

Color-octet status contributes at high-p_T range

$$3S_1^{[8]} \quad 1S_0^{[8]} \quad 3P_J^{[8]}$$

L.D.M.Es: the probability of C.O. status transition to J/ψ

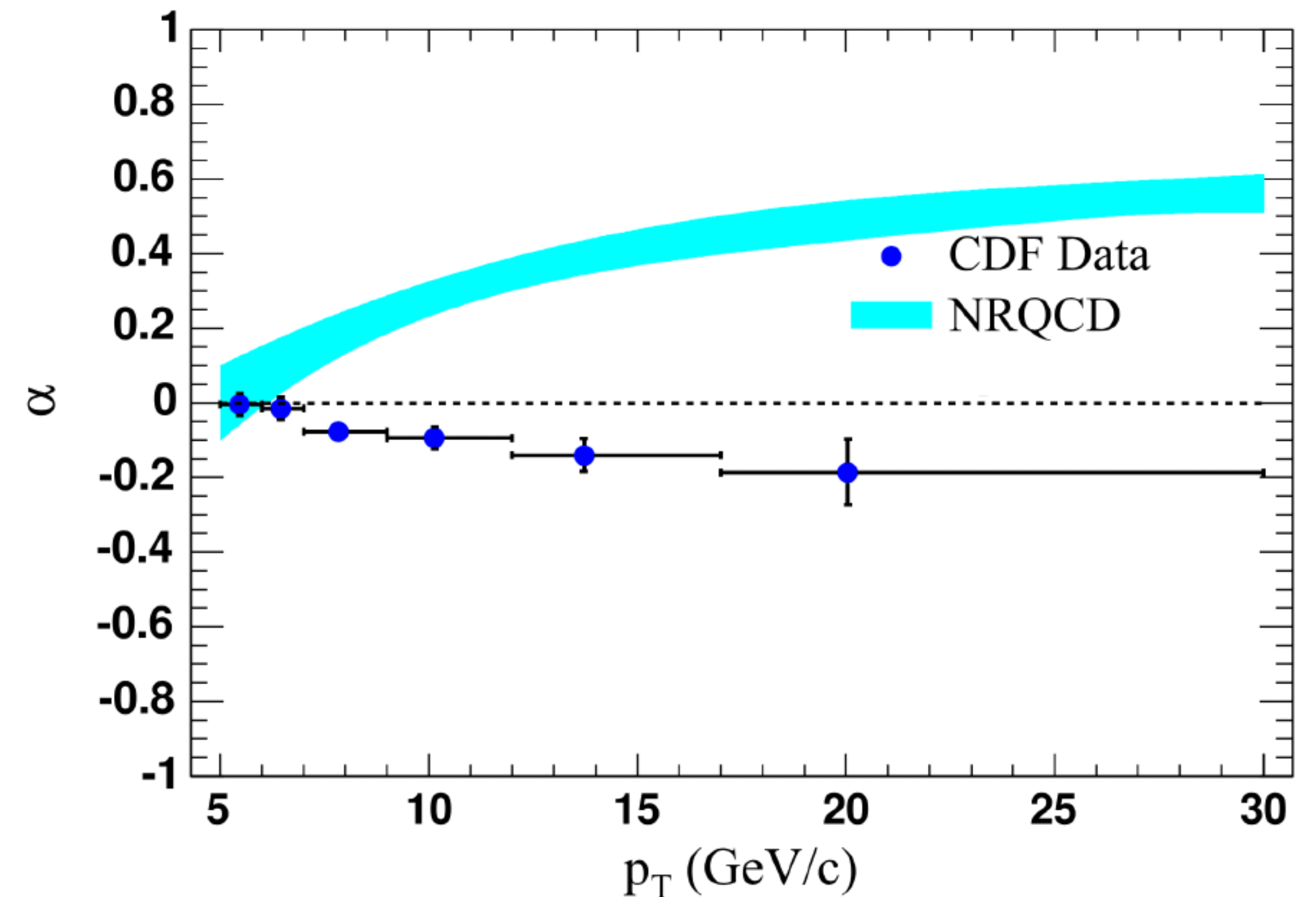
➤ The NLO NRQCD calculation can describe cross-section measurements at both RHIC and LHC

The universality issue and polarization puzzle in NRQCD

TABLE I. J/ψ NRQCD LDMEs from four different groups.

	$\langle \mathcal{O}(^3S_1^{[1]}) \rangle$ GeV ³	$\langle \mathcal{O}(^1S_0^{[8]}) \rangle$ 10 ⁻² GeV ³	$\langle \mathcal{O}(^3S_1^{[8]}) \rangle$ 10 ⁻² GeV ³	$\langle \mathcal{O}(^3P_0^{[8]}) \rangle$ 10 ⁻² GeV ⁵
Bodwin	0 ^a	9.9	1.1	1.1
Butenschoen	1.32	3.04	0.16	-0.91
Chao	1.16	8.9	0.30	1.26
Gong	1.16	9.7	-0.46	-2.14

PRL119,032001 (2017)



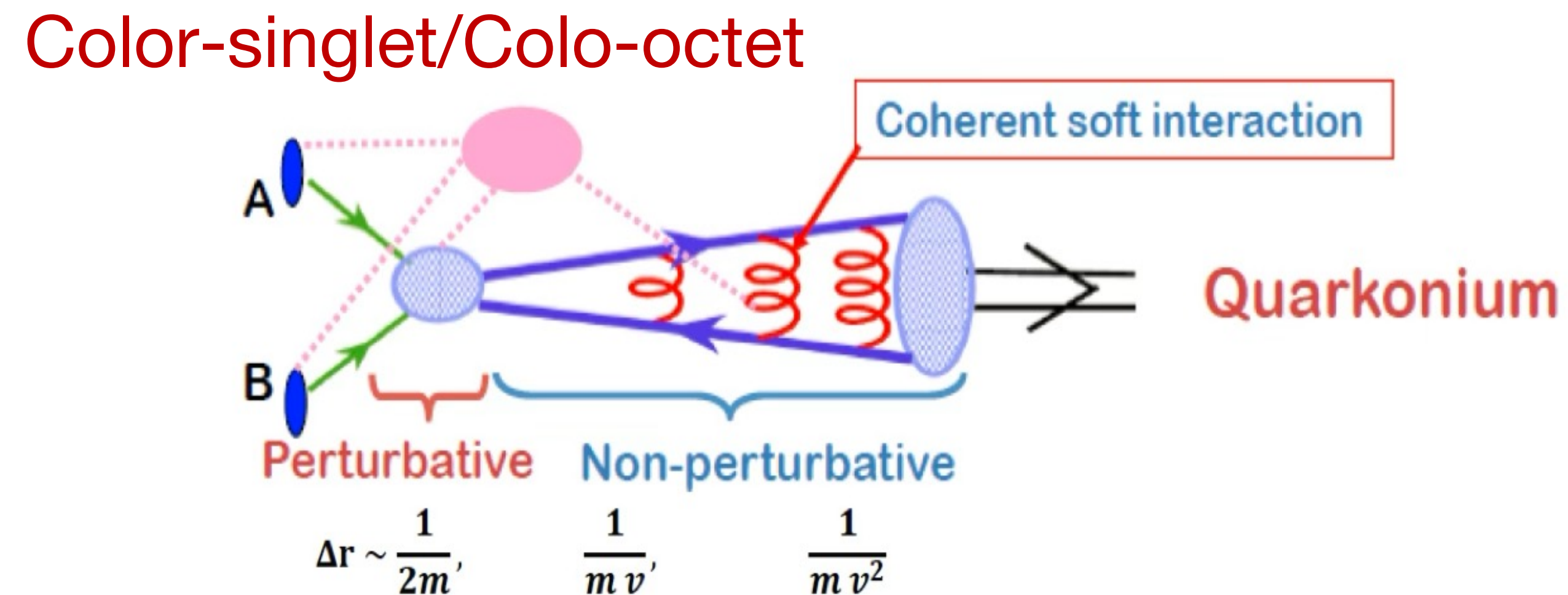
PRD 62,094005 (2000)

- Different LDMEs from p+p system and e⁺e⁻ collisions system
- Limited J/ψ polarization in data v.s. significant transverse polarization in model

Non-perturbative dynamics and polarization

- The $c\bar{c}$ pair non-perturbative evolution - J/ψ energy correlator

A question of N.P. that never been answered by any measurements due to its N.P. nature

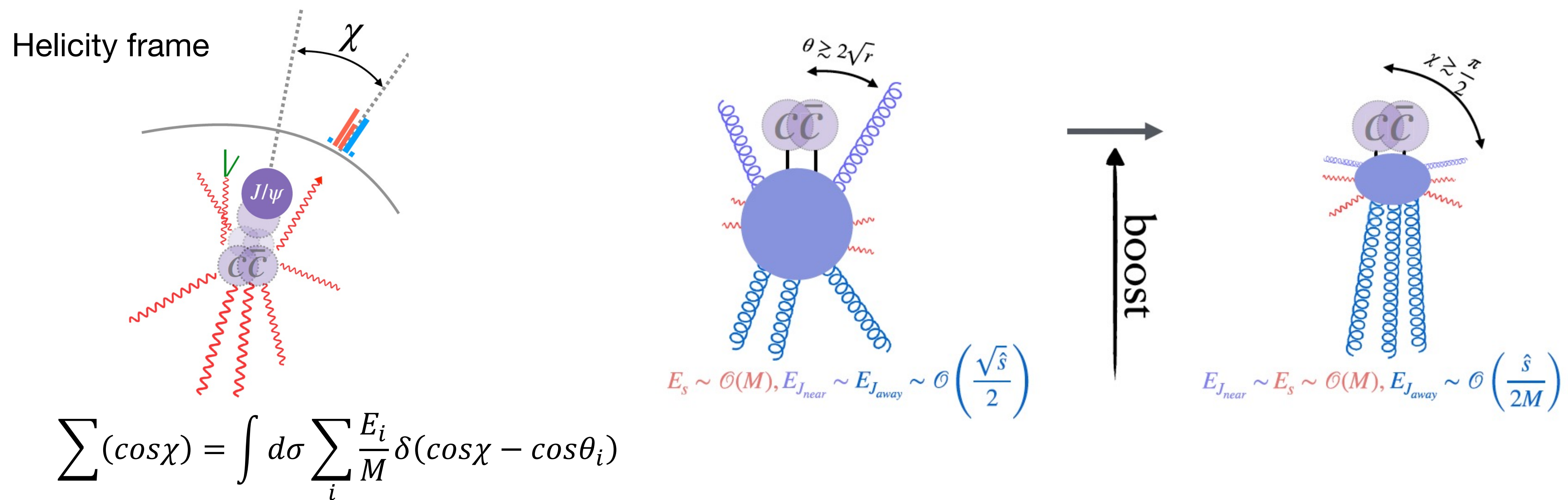


- Decompose the prompt J/ψ polarization in experiment - J/ψ polarization in HIC

J/ψ energy correlator

- Dead-cone effect + Lorentz boost to separate P.T and N.P.T process

PRL133,191901 (2024)



- Separation of **N.P.T process** from **P.T process** in $\cos\chi$

$(\cos\chi > 0)$

$(\cos\chi < 0)$

Hadronization impact on the J/ψ energy correlator measurement

Of interested: J/ψ - parton energy correlator

e.g. ${}^3S_1^{[8]} \rightarrow J/\psi ({}^3S_1) + \text{gluons}$

parton color reconnection

String/cluster hadronization

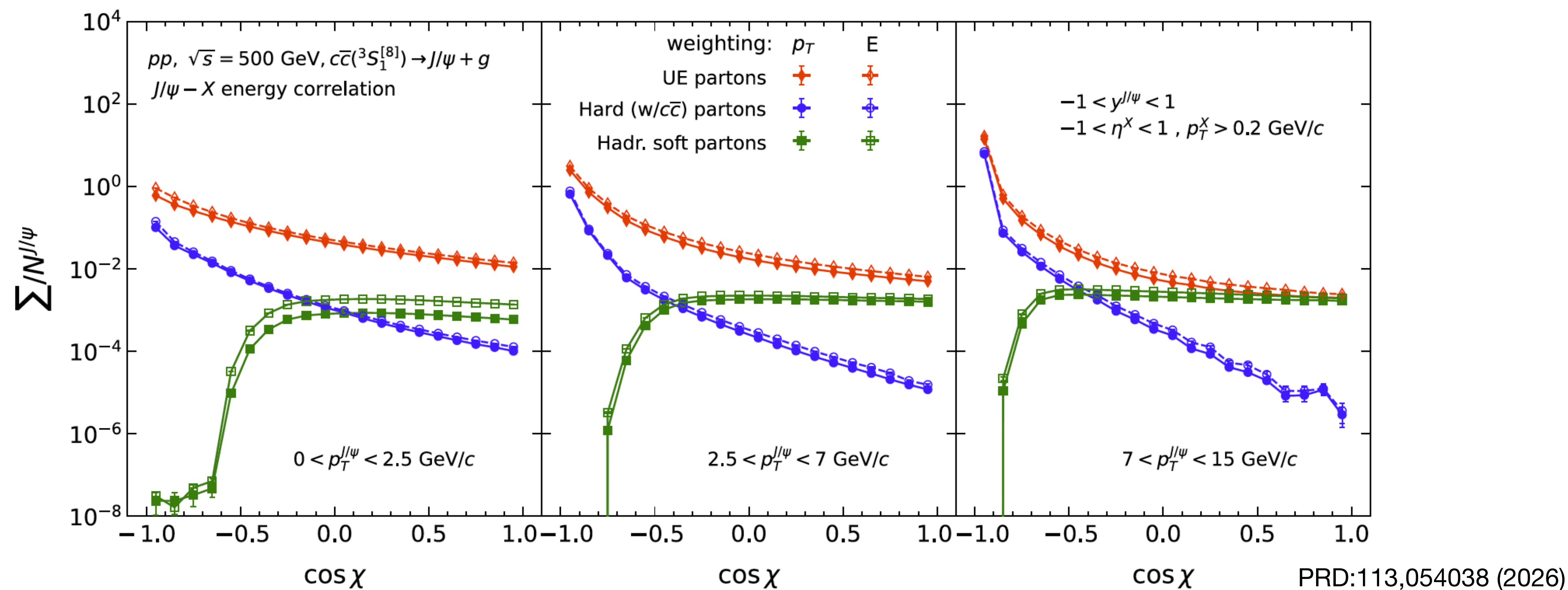
Primary hadron decay

- An event generator to mapping the energy correlator at the parton-level and hadron-level is needed!

Of measured: J/ψ - charged hadron energy correlator

Parton-level J/ψ energy correlator in Pythia8

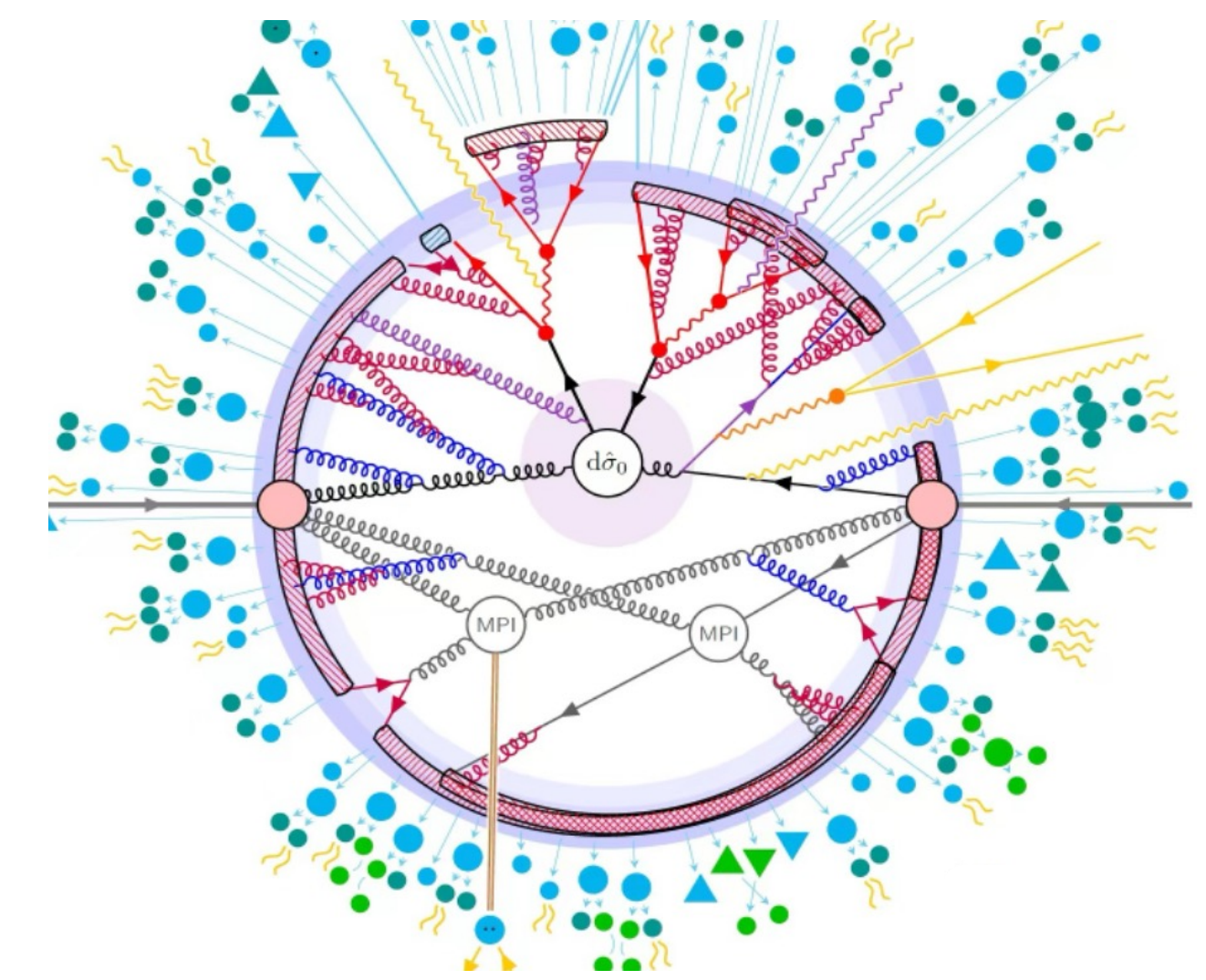
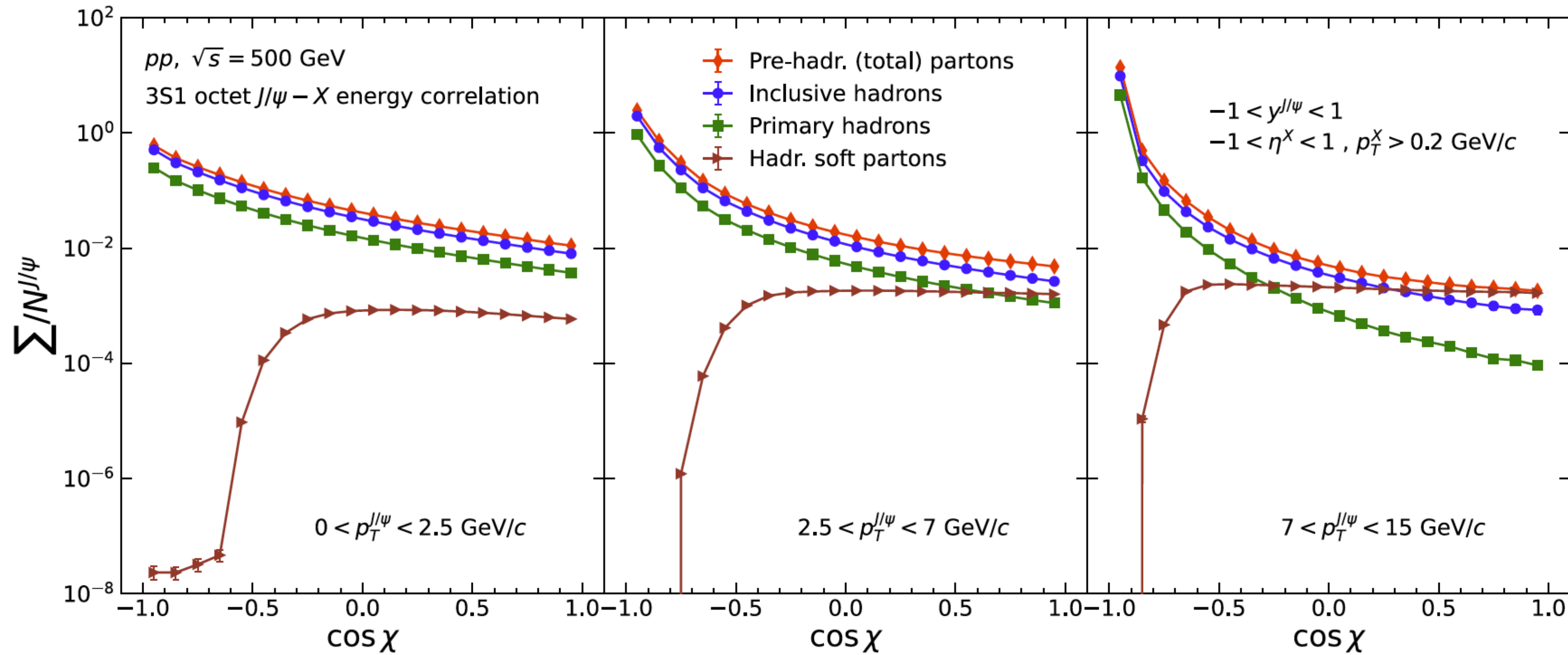
$$p + p \rightarrow J/\psi + X \text{ (parton)} \quad {}^3S_1^{[8]} \rightarrow J/\psi ({}^3S_1) + \text{gluons}$$



➤ The larger boost effect can help to suppress the MPI underlying-event contribution

Hadron-level J/ψ energy correlator in Pythia8

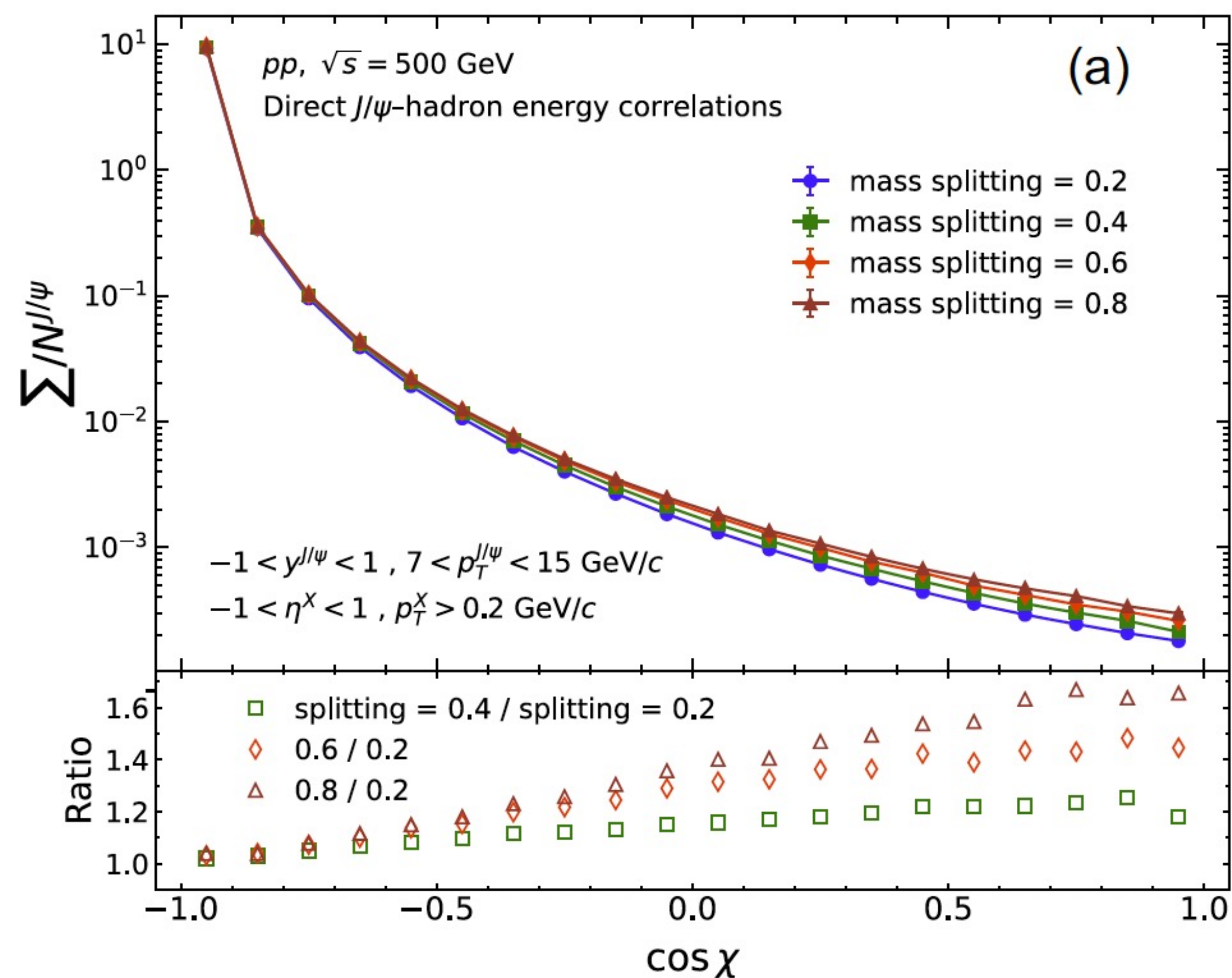
$$p + p \rightarrow J/\psi + X \text{ (parton)} \quad {}^3S_1^{[8]} \rightarrow J/\psi ({}^3S_1) + \text{gluons}$$



PRD:113,054038 (2026)

➤ Hadronization of soft gluon drastically reshapes the energy flow distribution at $\cos \chi > 0$ region

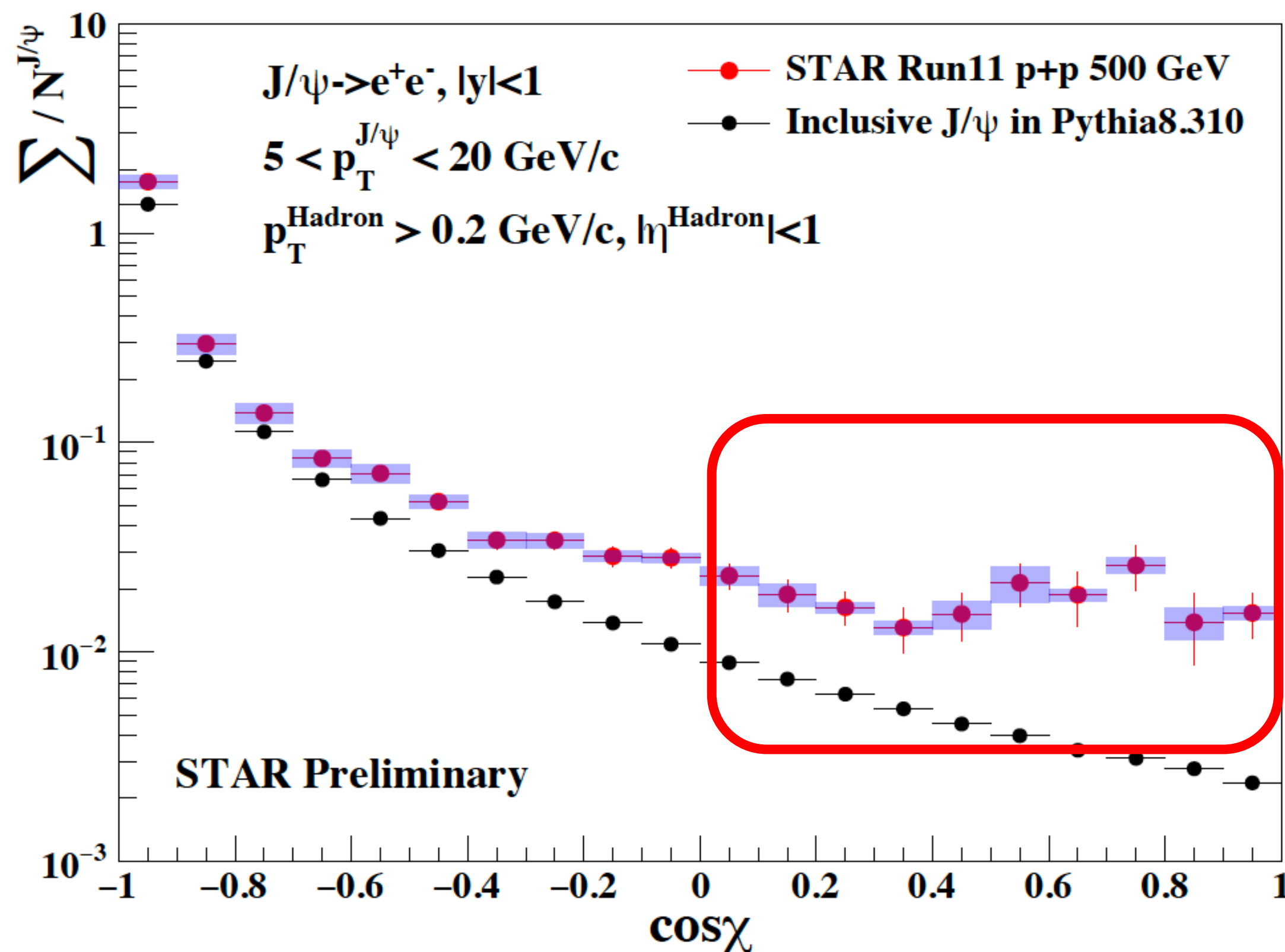
Sensitive to parton energy emission



PRD:113,054038 (2026)

- As the released energy increases, the correlator in the region with $\cos \chi > 0$ is enhanced
- Hadronization process materializes as an extra hadronic activity preferentially aligned with the J/ψ flight direction

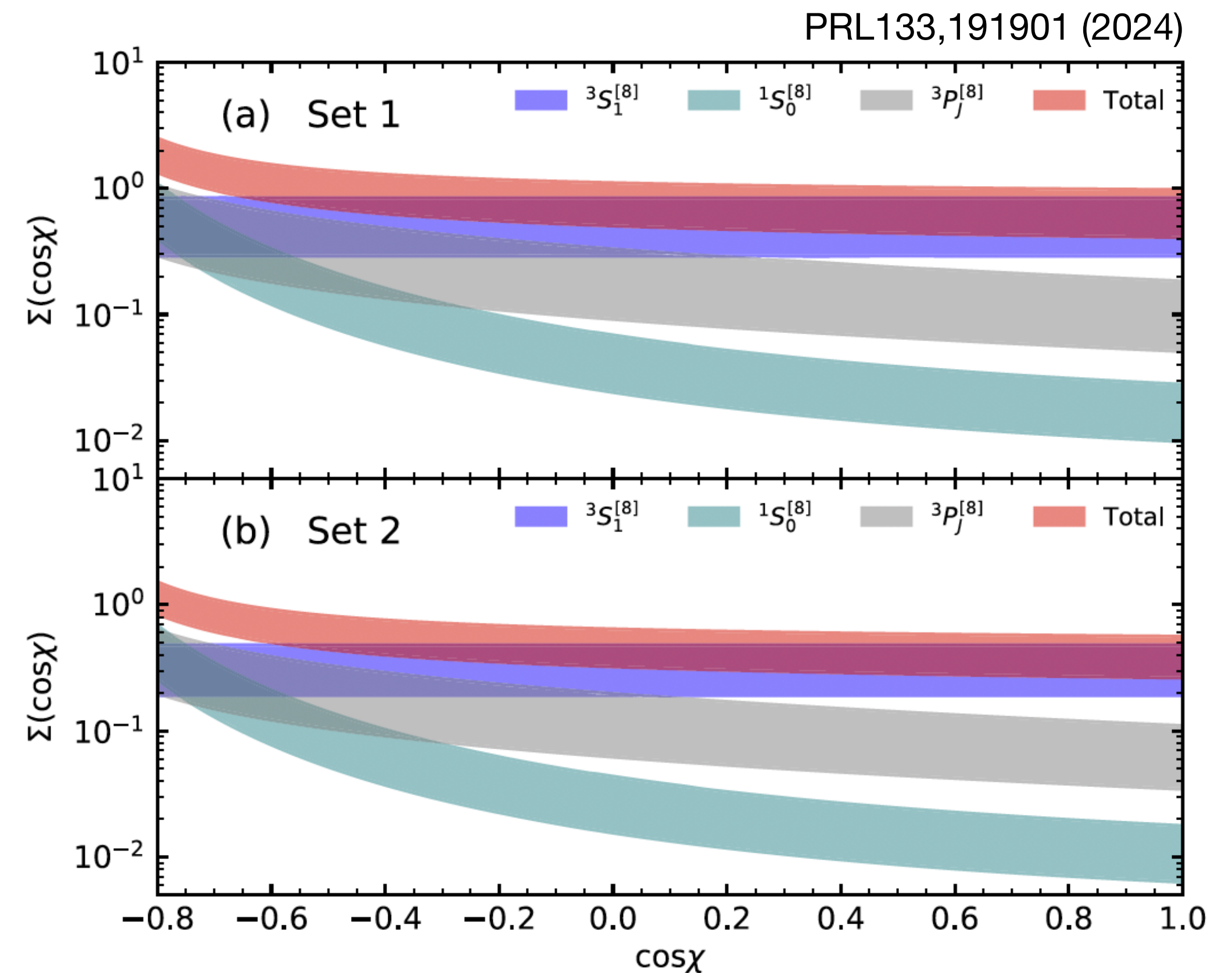
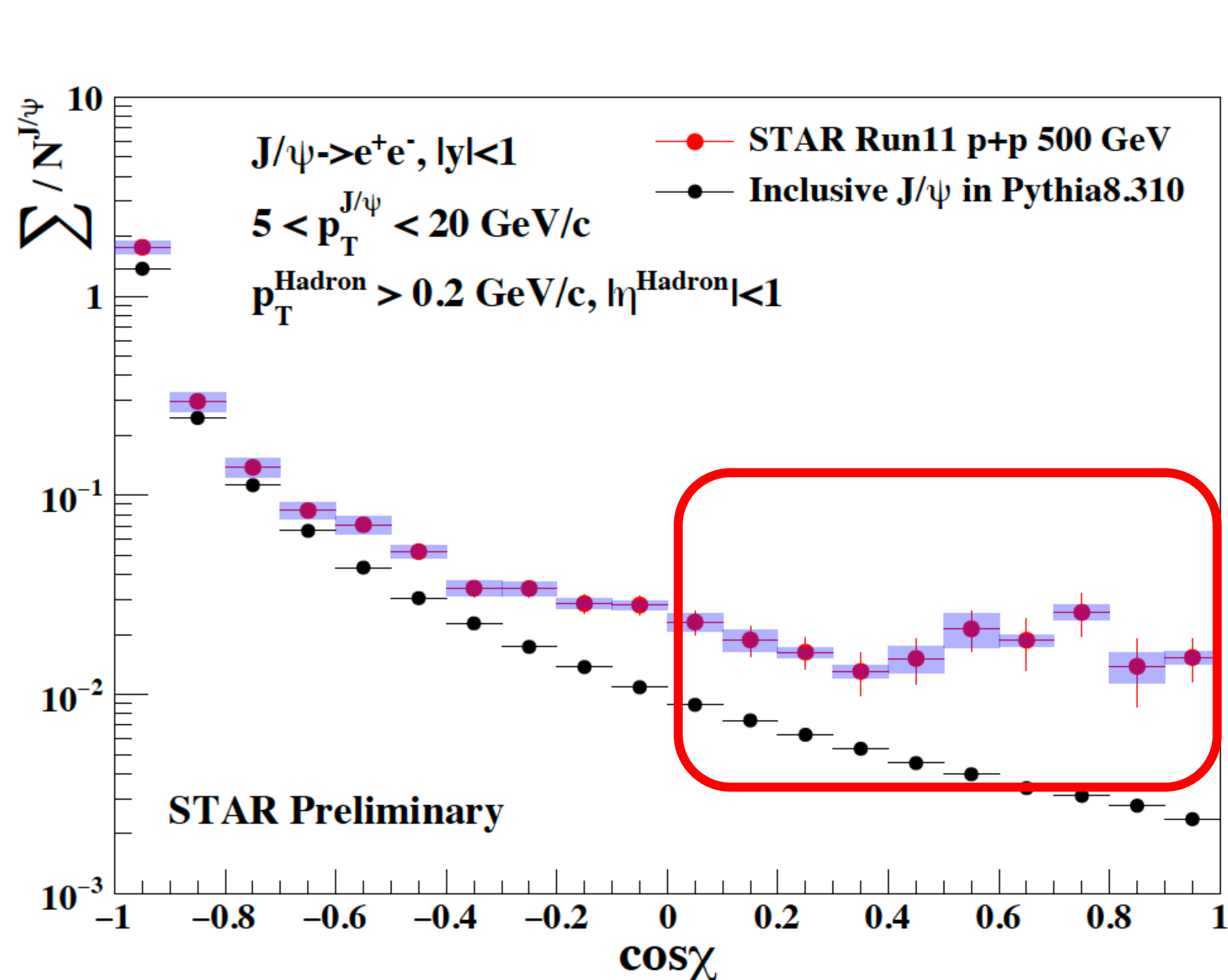
J/ ψ -charged hadron energy correlator in p+p @ 500 GeV



- No significant dependence on $\cos\chi$ for $\cos\chi > 0$
 - Pythia8 underestimated measurements
 - More hadrons released at forward range:
- indicated a different contribution of CO status in data and pythia8

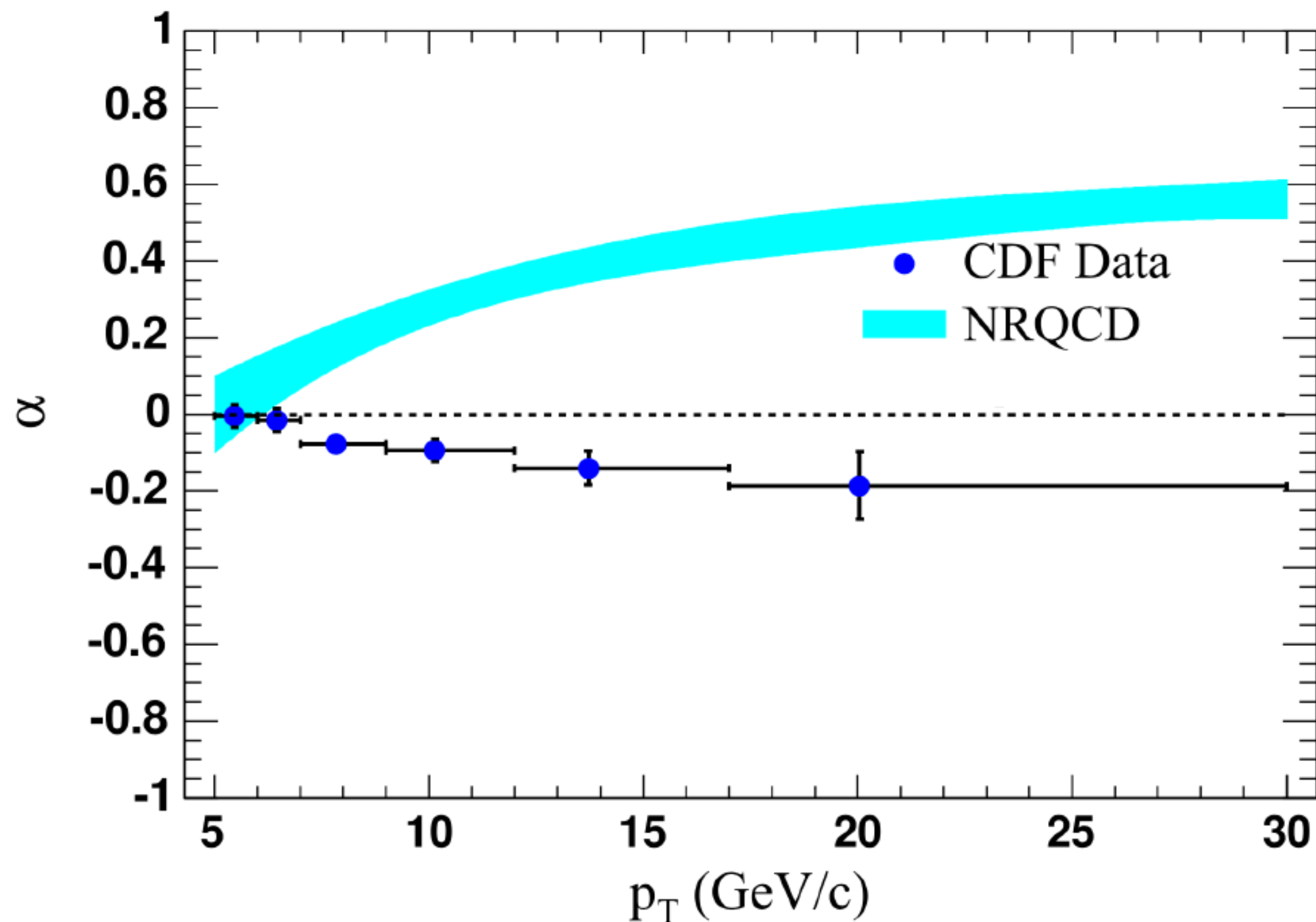
$${}^3S_1^{[8]}, \quad {}^1S_0^{[8]}, \quad {}^3p_J^{[8]}$$

J/ ψ -charged hadron energy correlator in p+p @ 500 GeV



- Consistent with a uniform radiative of gluons distribution from ${}^3S_1^{[8]}$ in NRQCD model at parton-level
stay tuned for the final physics interpretation!

Decompose the prompt J/ψ polarization in experiment



PRD 62,094005 (2000)

➤ Prompt J/ψ:

Direct 60% + Feed-down ($\chi_{cJ}^{30\%} + \psi(2S)^{10\%}$)

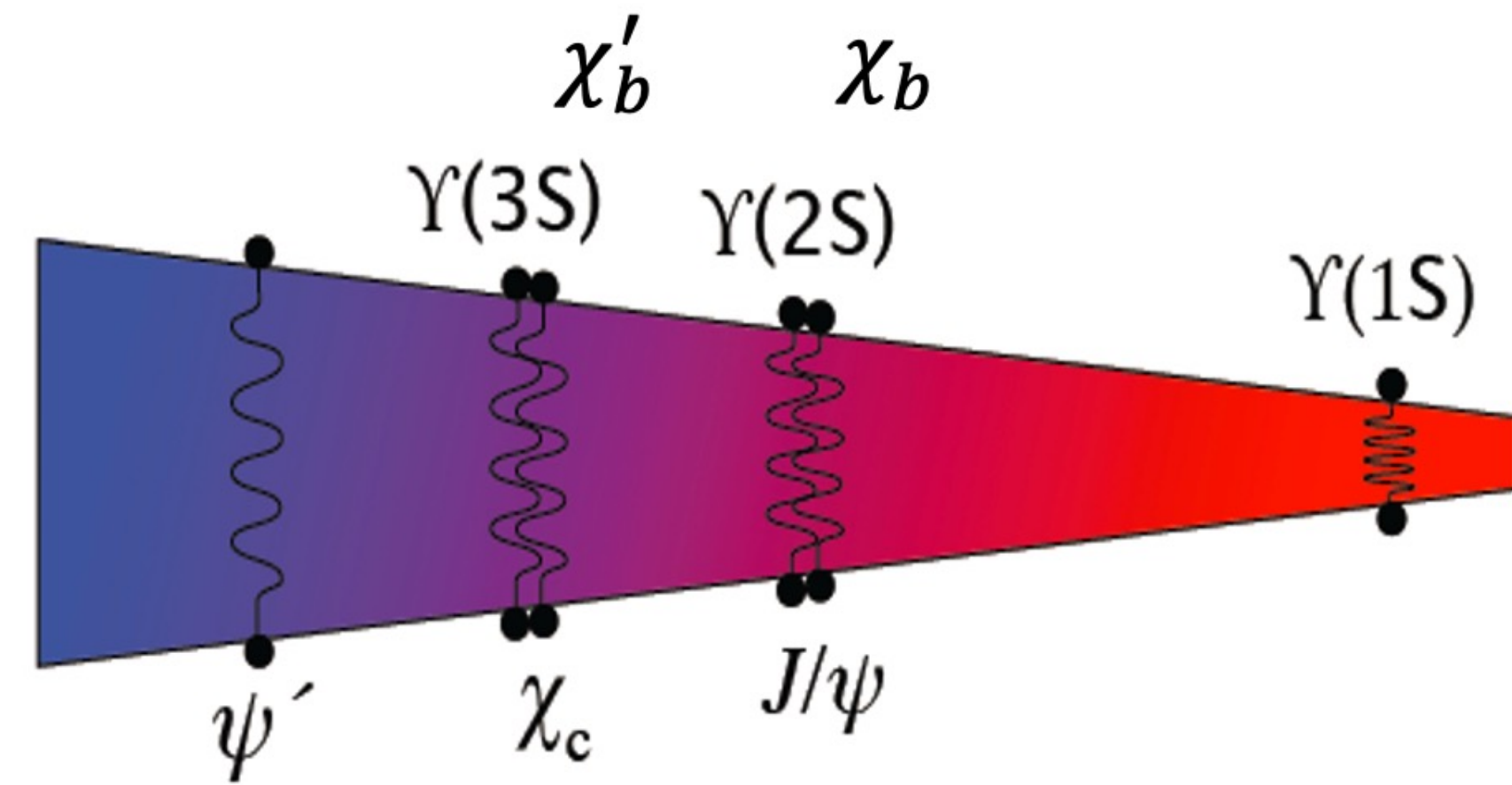
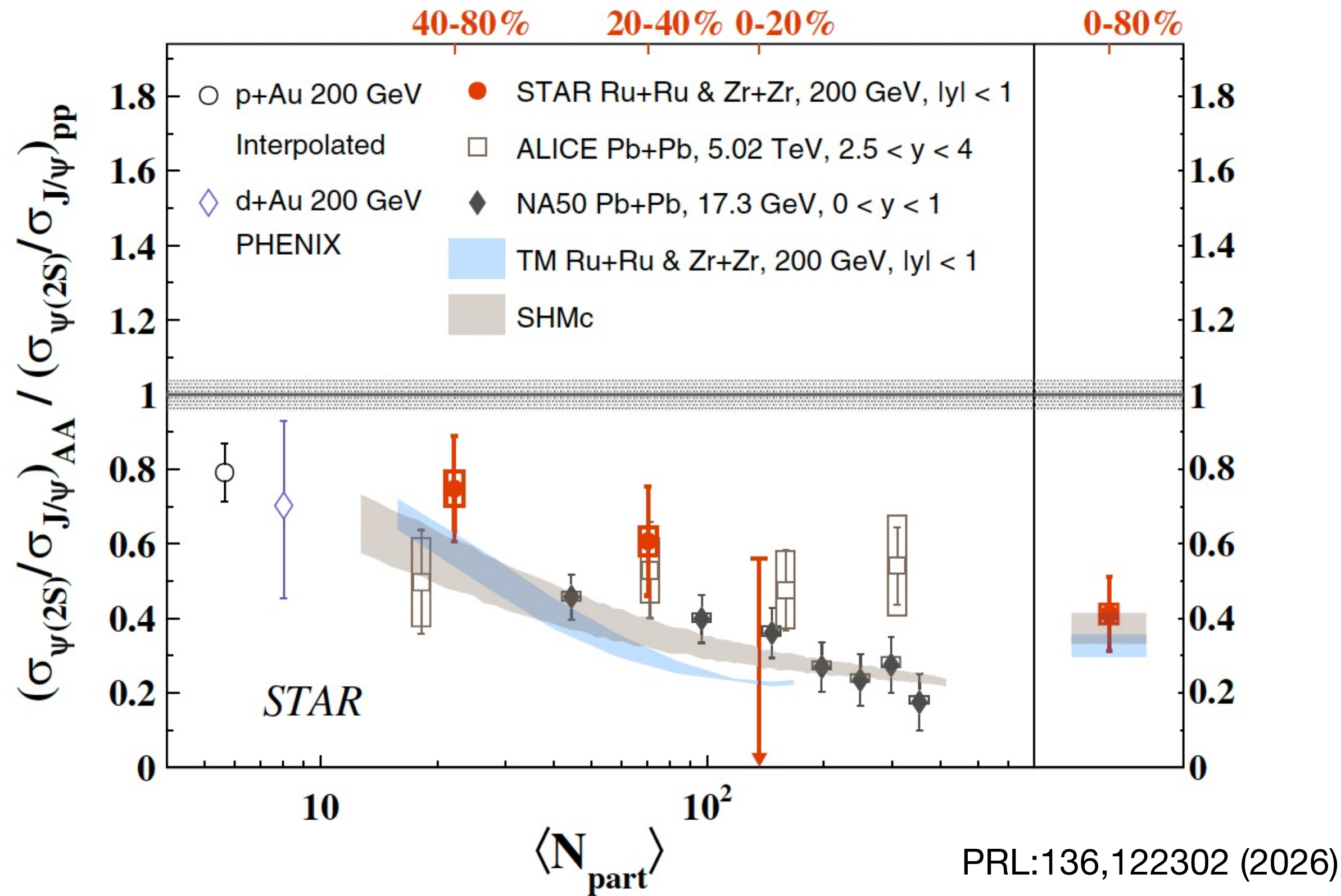
$\psi(2S) \rightarrow J/\psi + \pi\pi$ Practically unchanged

$\chi_{cJ} \rightarrow J/\psi + \gamma$ Alters polarization

➤ Different polarization among different charmonium

CMS, PRL 124,162002 (2020)

Charmonium sequential melting in HIC



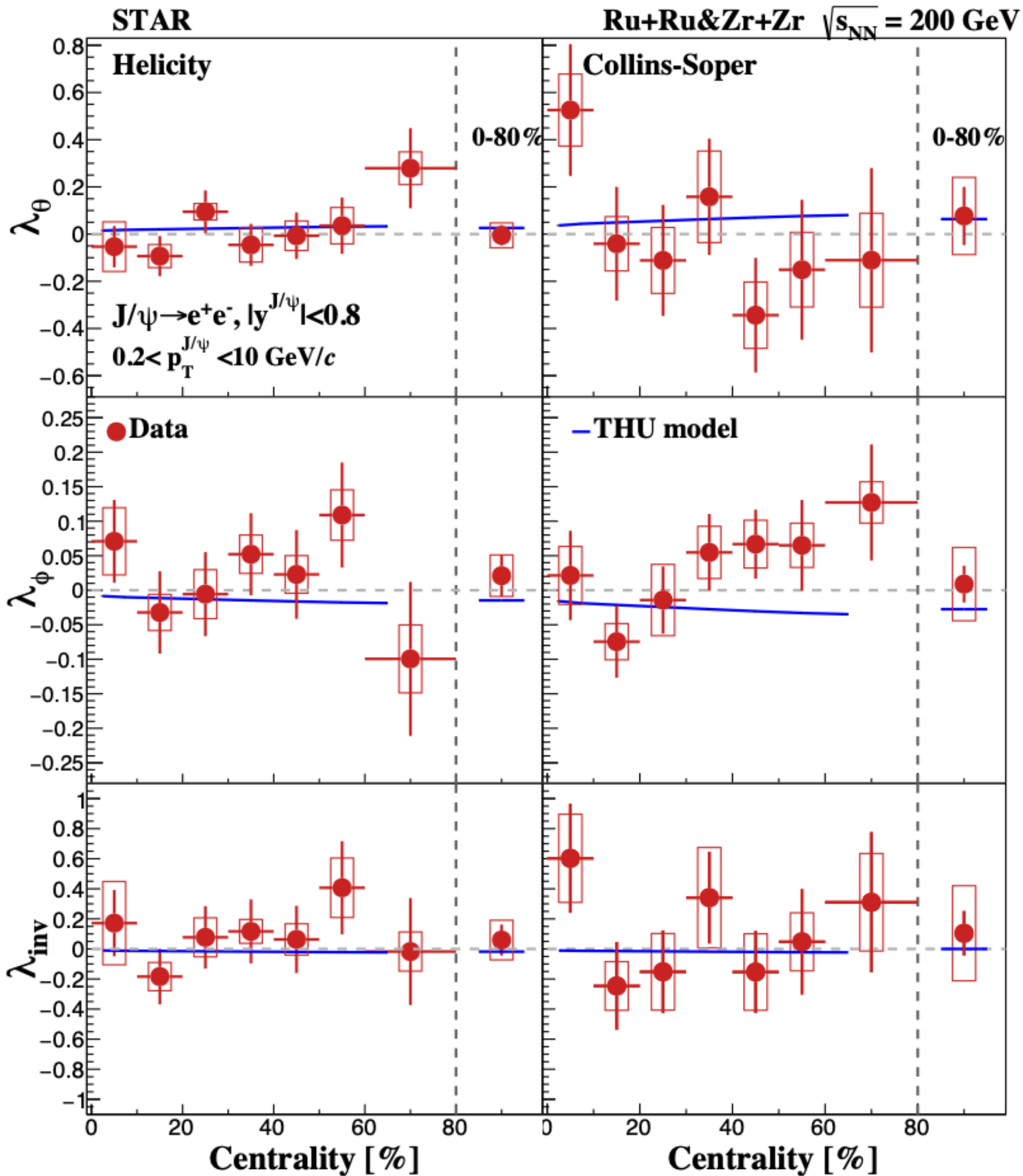
Proper polarization axis: critical for polarization measurements

➤ “Prompt” J/ψ: direct + **Feed-down** + regeneration

14~20%

~25%

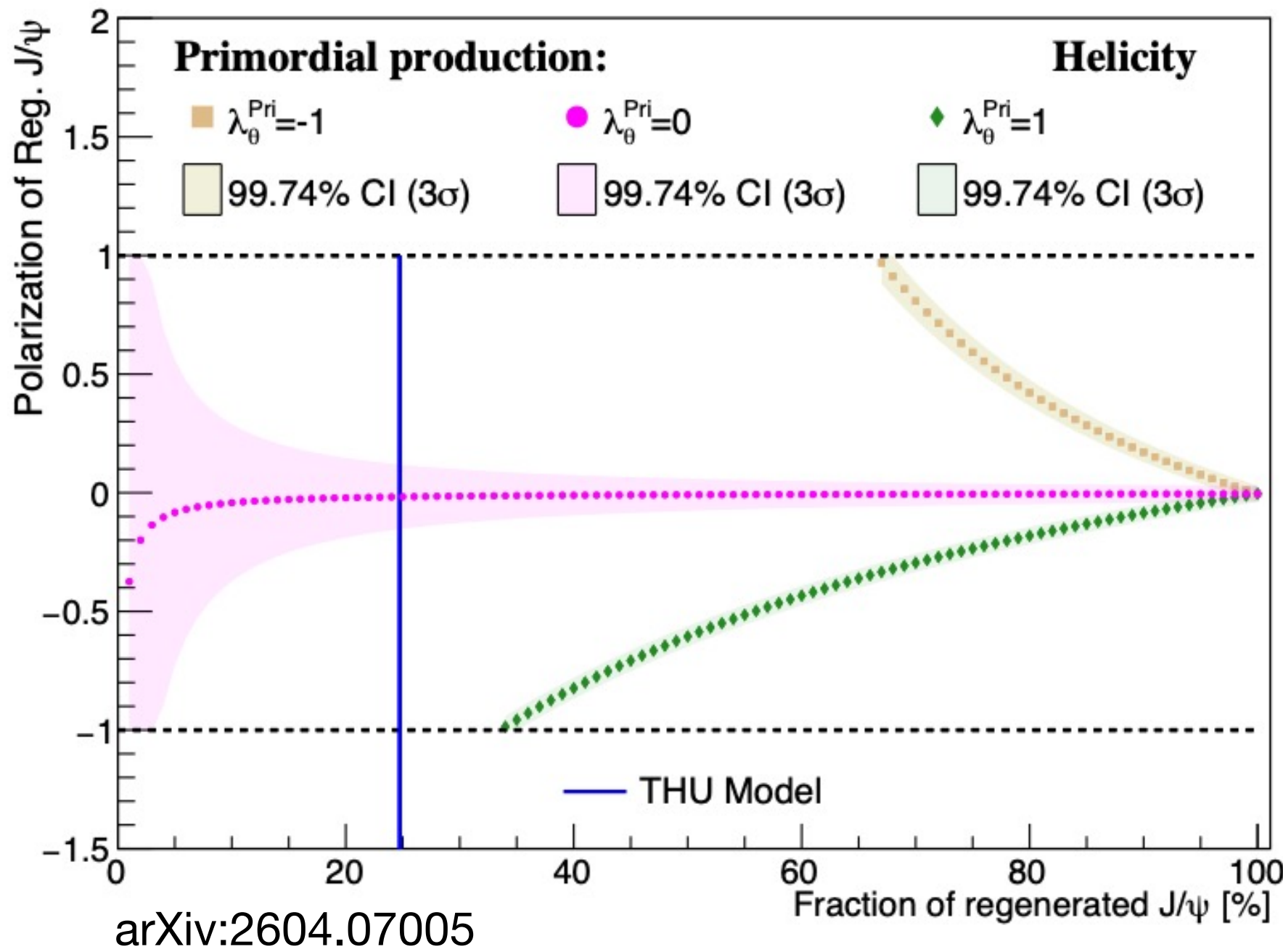
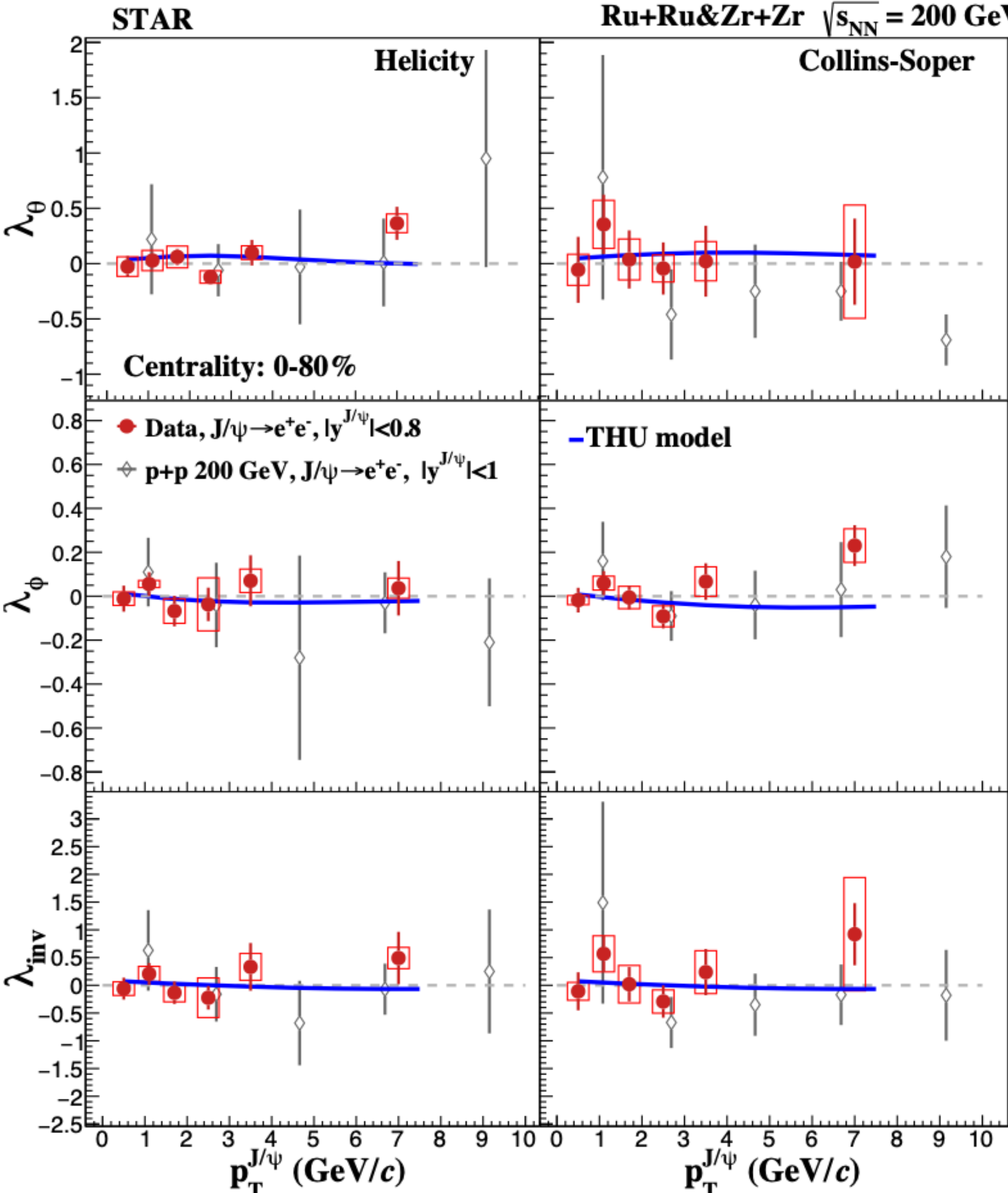
J/ψ spin measurement at RHIC-STAR



- $\lambda_\theta, \lambda_\phi$ are found to be consistent with zero and exhibit no significant centrality dependence
- Result are consistent with the THU model
 -Model assuming that J/ψ produced via excited-state decays carries zero polarization

arXiv:2604.07005

J/ψ spin measurement at RHIC-STAR



- $\lambda_\theta, \lambda_\phi$ are consistent with 0 and exhibit no significant dependence on p_T
- Provide a strong constrain on the polarization of regenerated J/ψ in the helicity frame

Summary

- J/ψ as a multi-scale system is ideal for QCD study
- J/ψ-energy correlator: Non-perturbative evolution of $c\bar{c}$ pair
 - The hadronization of soft gluon drastically reshapes the energy flow distribution at the $\cos\chi > 0$ region in Pythia8
 - The measurements shows no significant $\cos\chi$ dependence in the non-perturbative sensitive range → **stay tuned for the final physics interpretation**
- J/ψ polarization in HIC
 - A different “prompt” J/ψ component in HIC than in p+p due to charmonium sequential melting
 - The polarization parameters are found to be consistent with zero and exhibit no significant p_T and centrality dependence

Thank you!

J/ ψ energy correlator

Proton+proton

