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Measurement of J/ψ energy correlator in p+p collisions at $\sqrt{s}$ = 500 GeV at STAR

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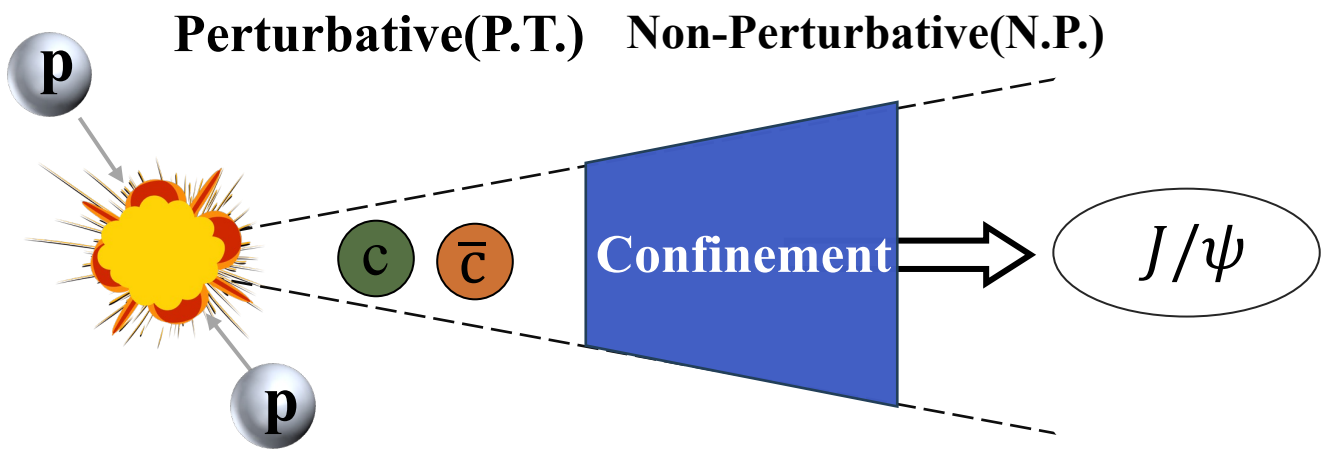
Outline

- Motivation
  - J/ψ production mechanism
  - J/ψ energy correlator
- J/ψ energy correlator measurement
- Summary and outlook

Why J/ψ?

- ✓ Key features of strong interaction： Asymptotic freedom and color confinement
- ✓ m_c~1.3 GeV: $c\bar{c}$ pairs are produced in hard process

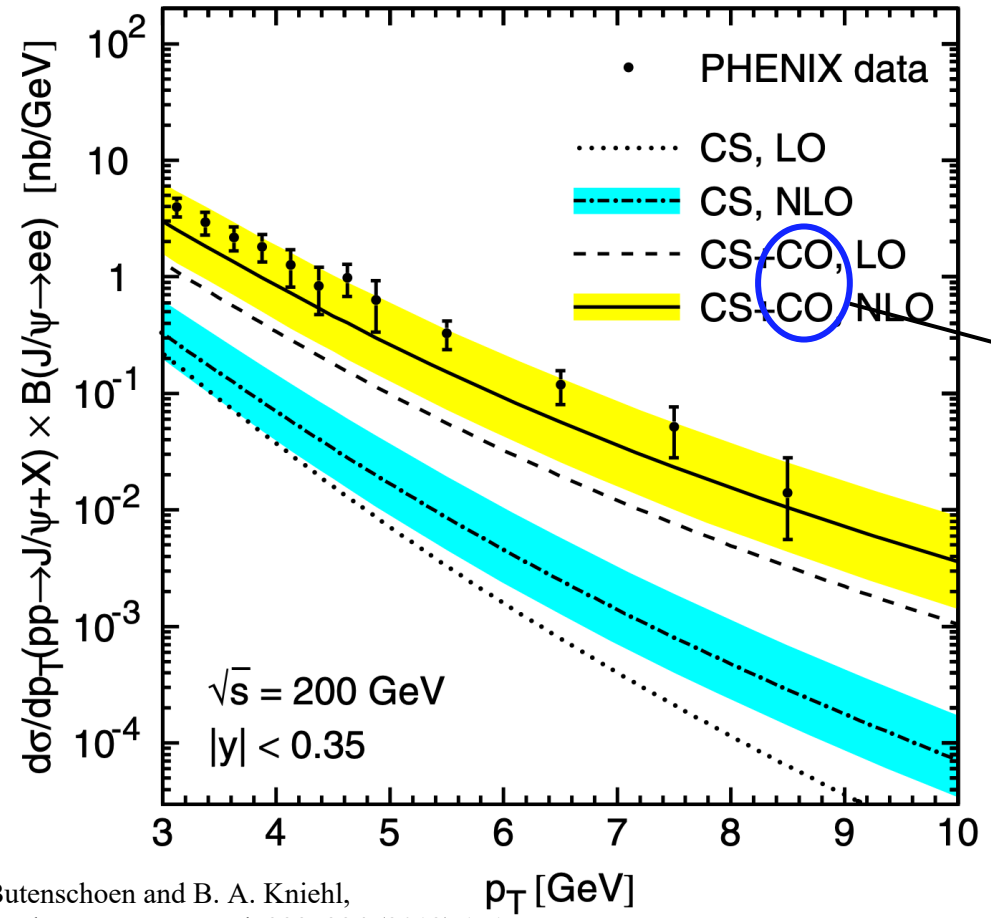


- ➢ **J/ψ production process is an ideal testing ground for QCD**

J/ψ production mechanism

✓ Factorization of J/ψ production: Perturbative QCD + phenomenological model (N.P.)

- Models: NRQCD, CSM, CEM, ICEM et al.



M. Butenschoen and B. A. Kniehl,
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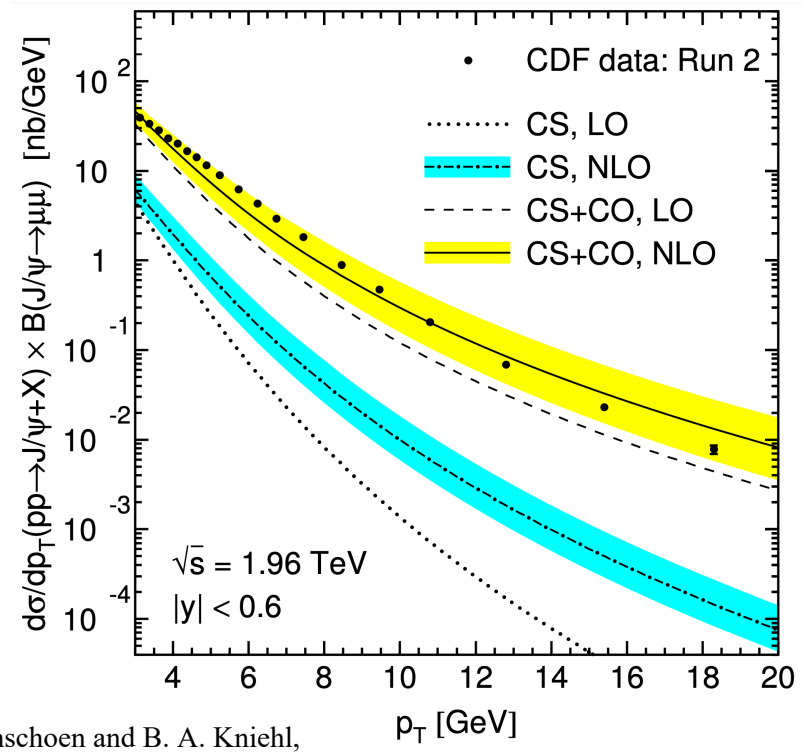
The color octet states is dominat at the RHIC energy according to NRQCD model predicted

Polarization challenge

✓ Cross section



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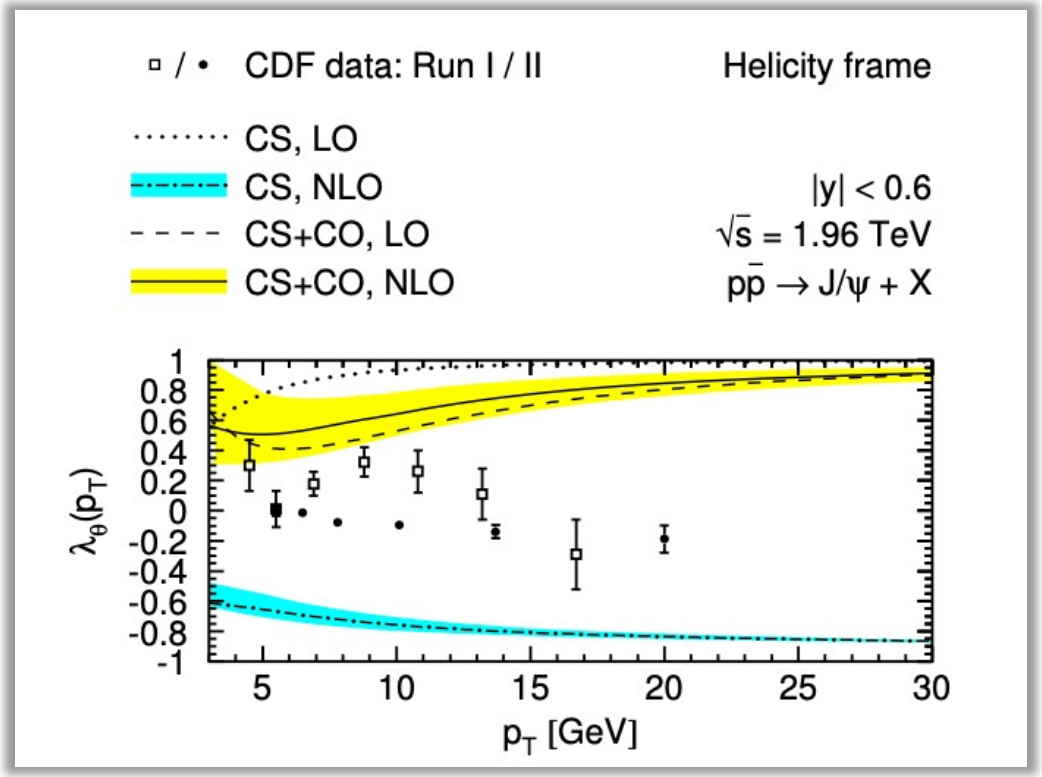
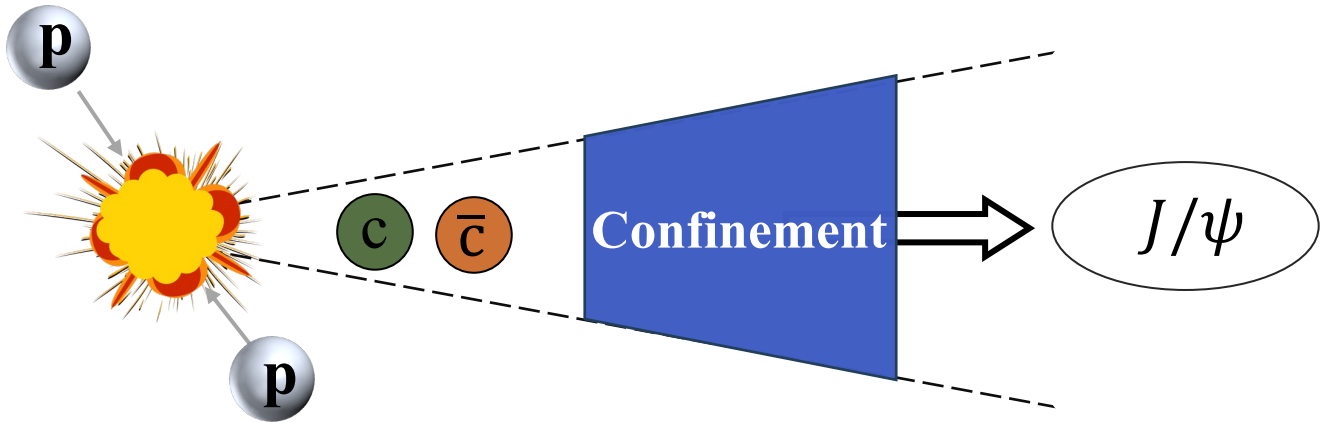
✓ Polarization



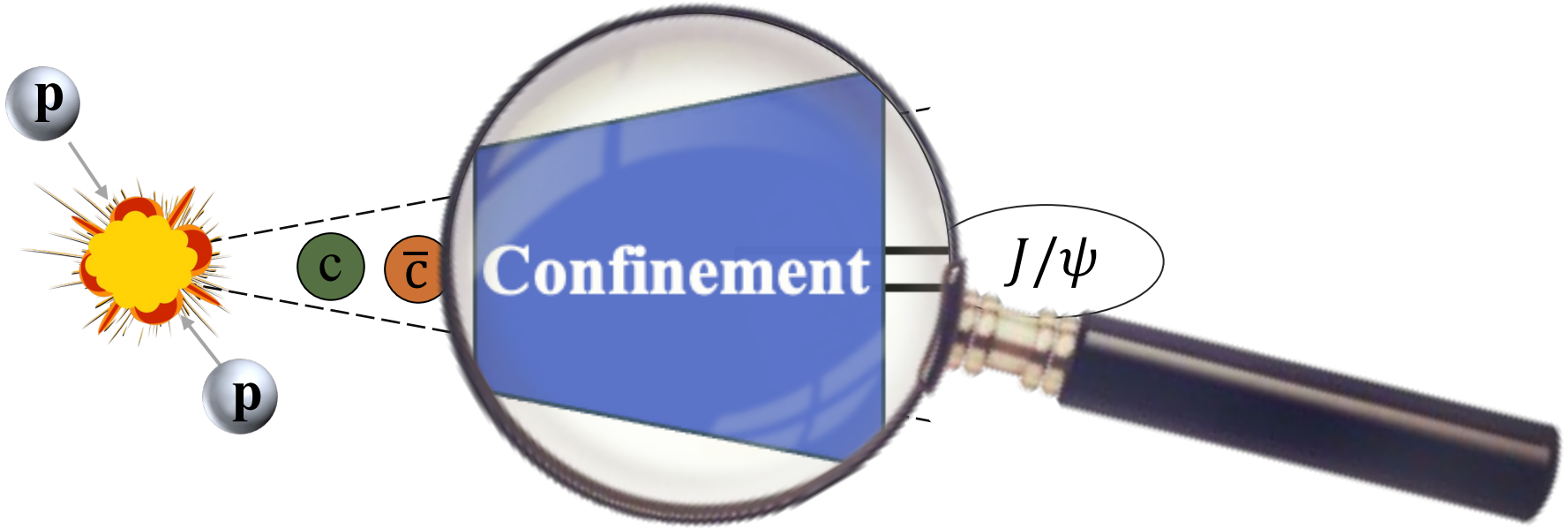
- The cross section and polarization cannot be simultaneously described
- **J/ψ production mechanism in elementary collisions is not fully understood**

Towards a solution



- Experimental decomposition of the J/ψ production process (P.T. and N.P.) is very important

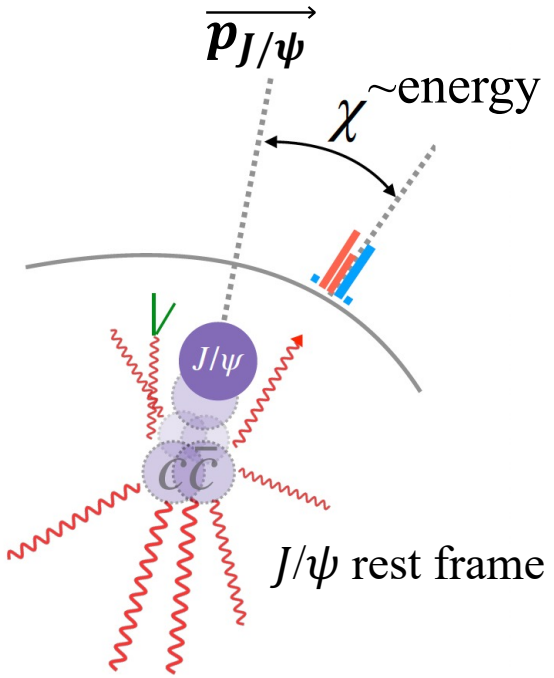
Towards a solution



- Experimental decomposition of the J/ψ production process (P.T. and N.P.) is very important
- J/ψ energy correlator a new observable for the first to direct sensitive to hadronization/confinement process

J/ψ energy correlator

✓ J/ψ energy correlator: average energy emitted during the hadronization process



$$\Sigma(cos\chi) = \int d\sigma \sum_i \frac{E_i}{M} \delta(cos\chi - cos\theta_i)$$

A. Chen, X. Liu, and Y. Ma,
Phys. Rev. L 133(19):191901, (2024)

- J/ψ as a tagged particle

  Specified hadronization process ($\boldsymbol{c\bar{c} \rightarrow J/\psi + X}$)

- In J/ψ rest frame at $cos\chi > 0$

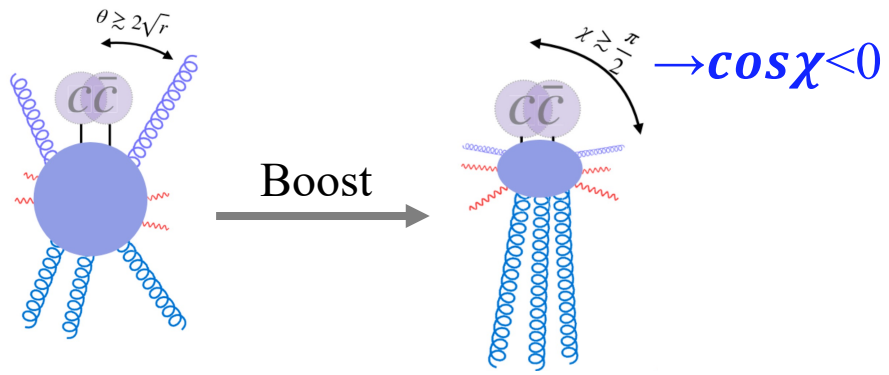
  an opportunity to separate of P.T process and **N.P process**

  $\boldsymbol{(cos\chi < 0)}$ $\boldsymbol{(cos\chi > 0)}$

1) Constraining energy released/ distribution during hadronization

2) Distinguishing production models

J/ψ energy correlator: shedding light on hadronization



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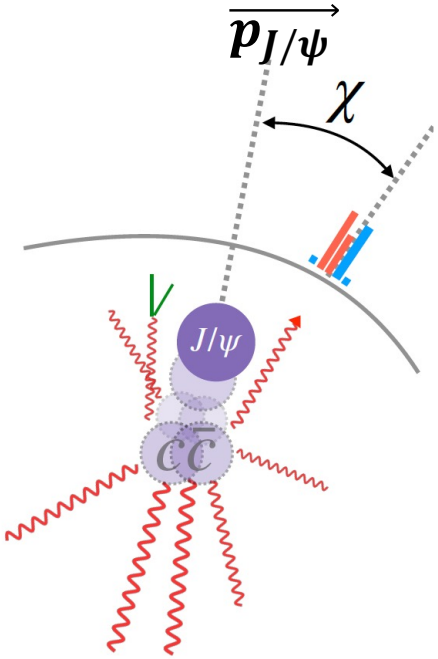
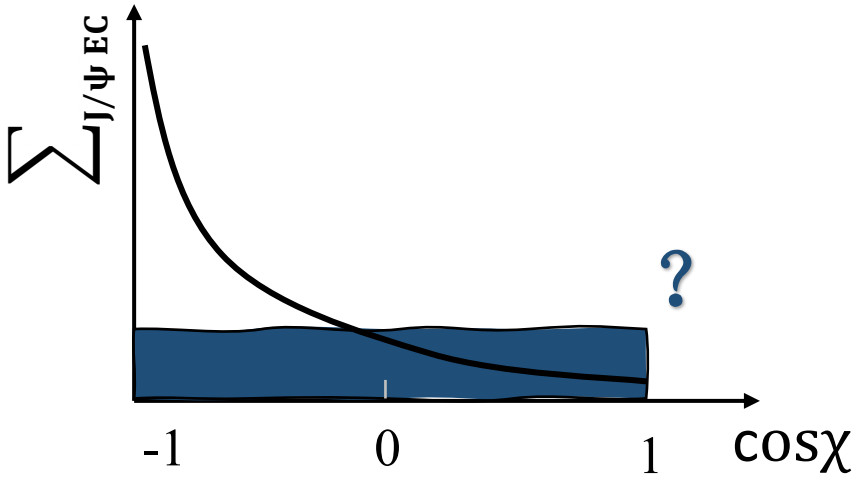


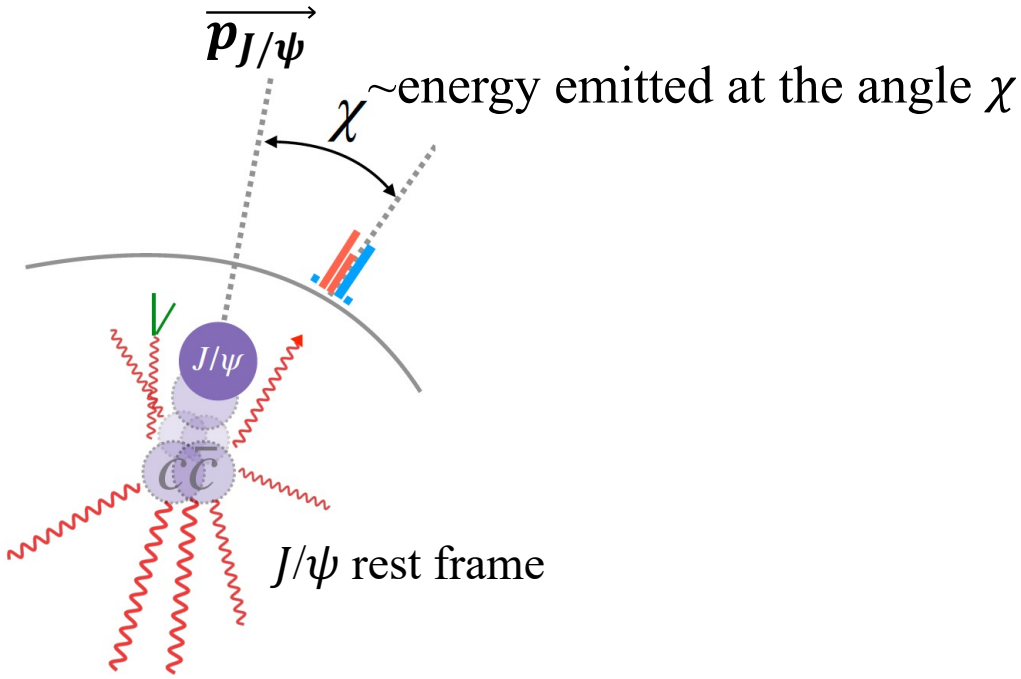
$$\sum_{J/\psi\ EC} = \sum_{J/\psi\ EC,P.T.} + \sum_{J/\psi\ EC,N.P.}$$



- Contribution from perturbative processes is suppressed for $cos\chi>0$
- **Contribution from hadronization could be large for $cos\chi>0$**

J/ψ energy correlator

✓ J/ψ energy correlator: average energy emitted during the hadronization process



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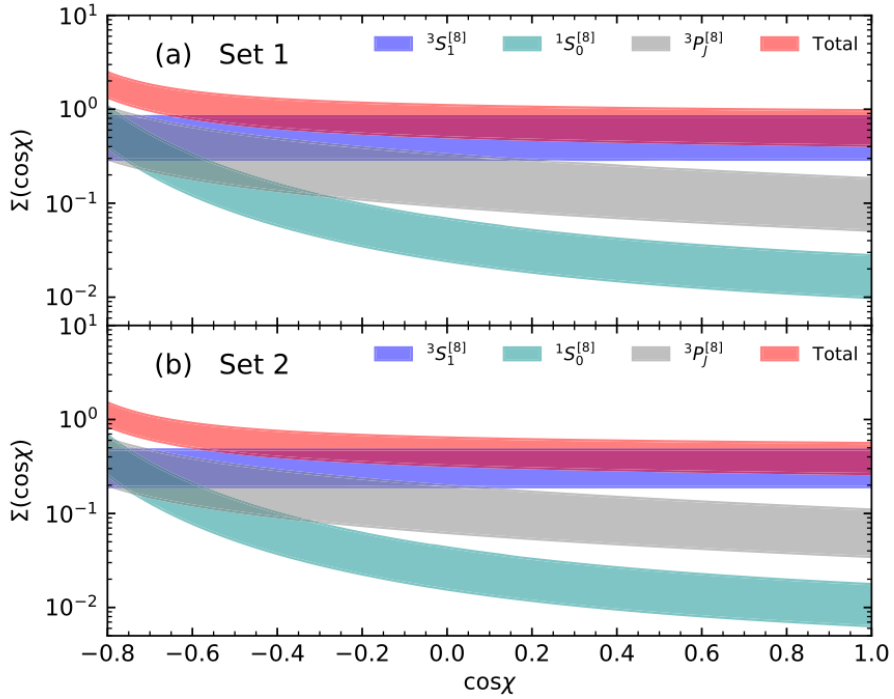
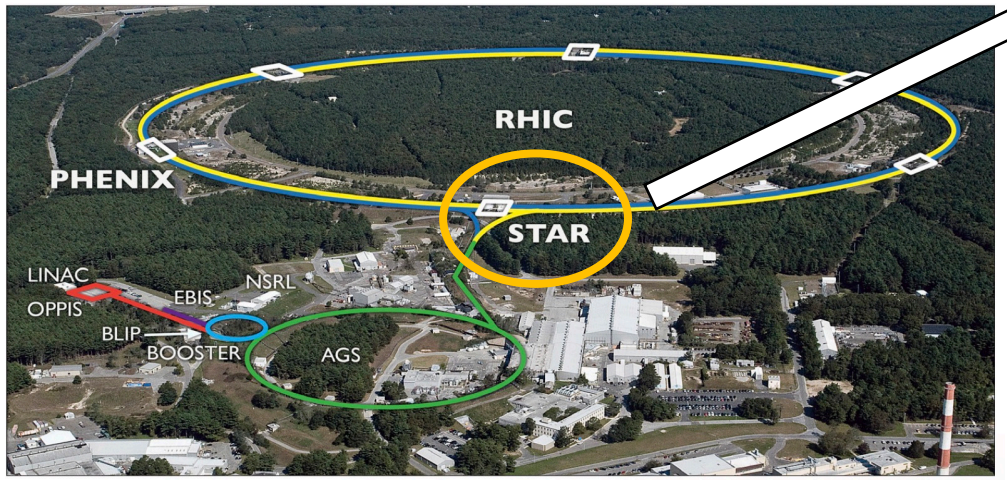


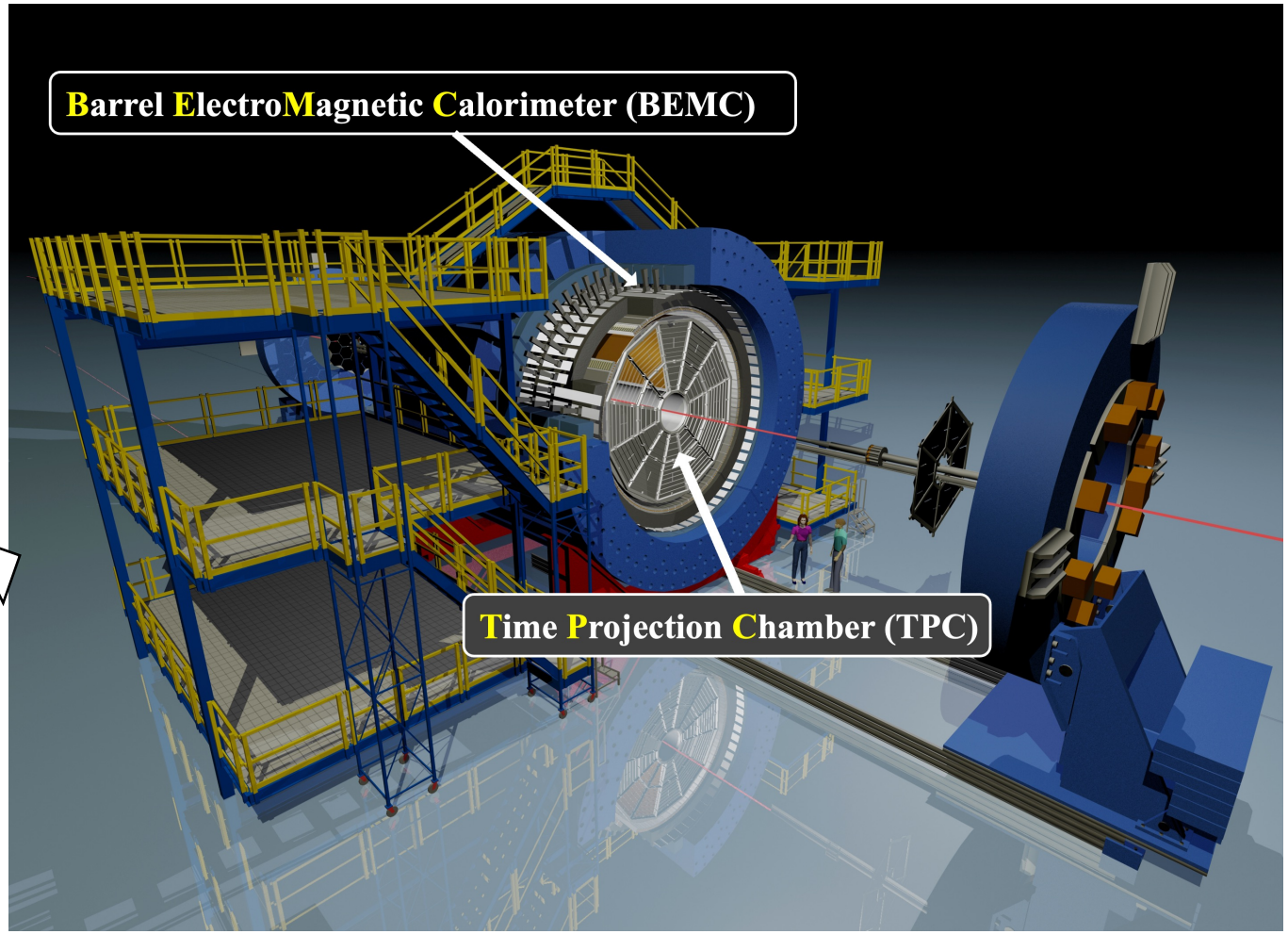
Theoretical predictions for J/ψ energy correlator in pp collision at $\sqrt{s}$=7 TeV.

➢ **Distinguish between different models**

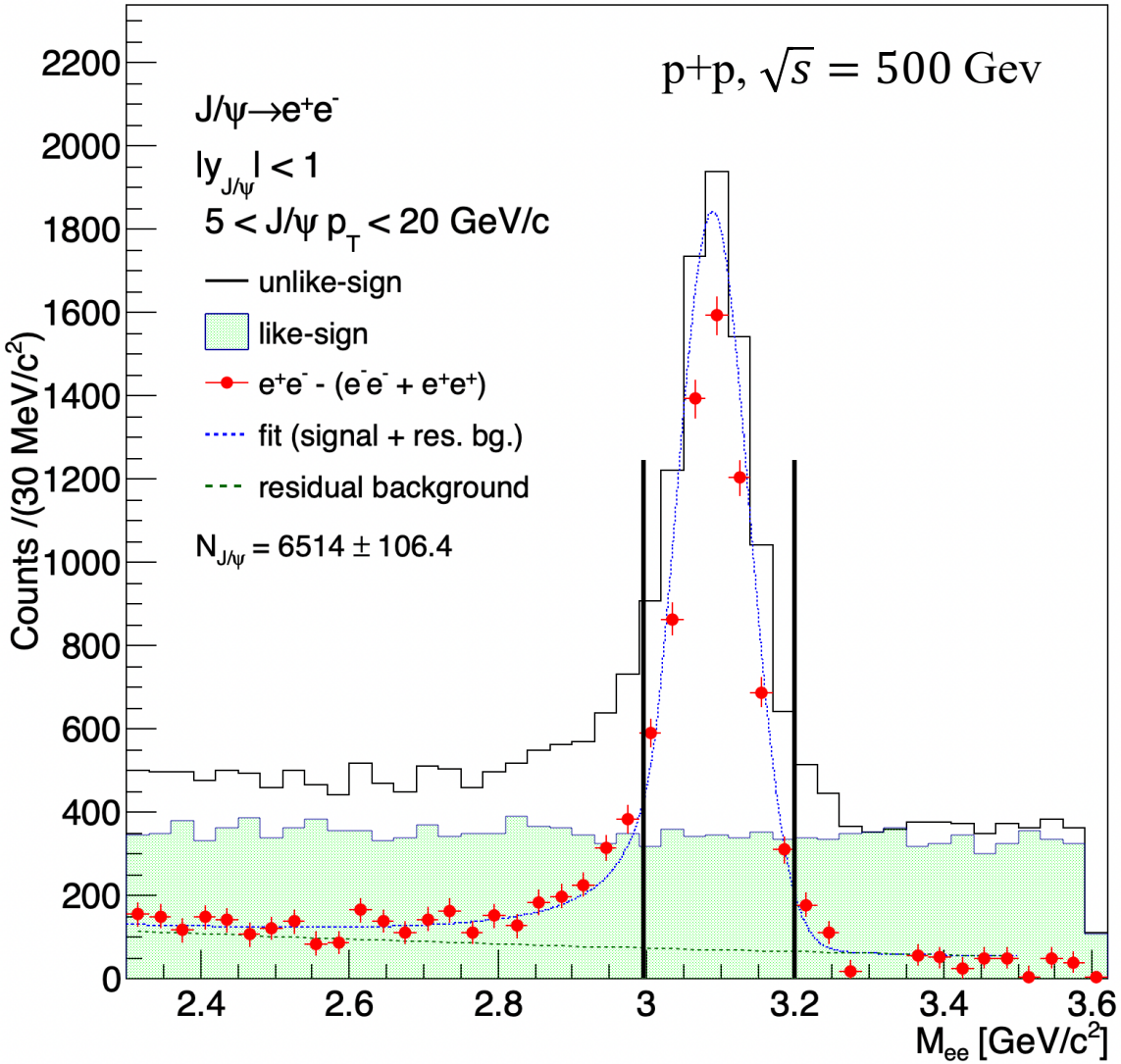
The Solenoid Tracker At RHIC (STAR)

- TPC:
  - Tracking – momentum
  - Particle identification – dE/dx
- BEMC:
  - Trigger on high energy electron
  - Electron identification – p/E



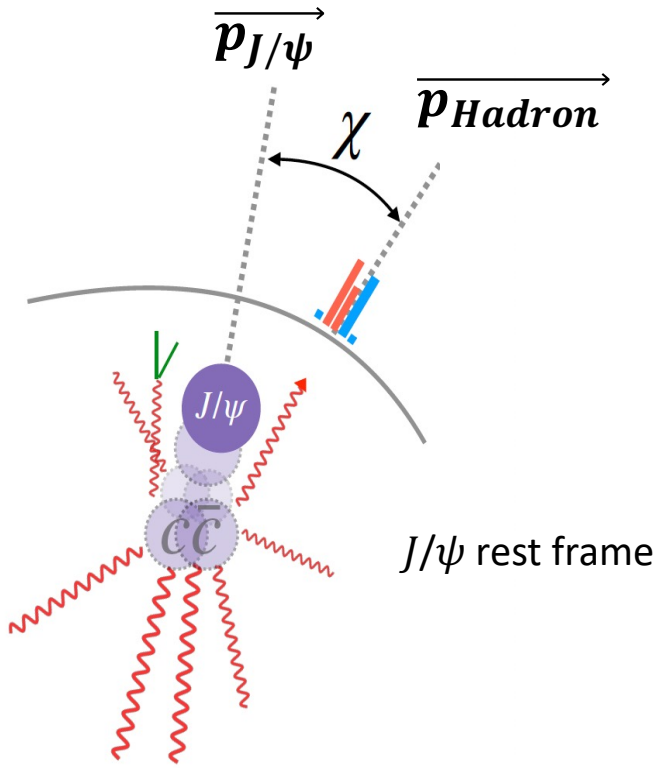


J/ψ signals



- Decay channel : $J/\psi \rightarrow e^+e^-$, |y|<1 with p+p $\sqrt{s}$ = 500 GeV
- J/ψ p_T range: 5-20 GeV/c
- Mass range：[3.0, 3.2] GeV/c^2

Analysis strategy



J/ψ rest frame

$$\Sigma(cos\chi) = \int d\sigma \sum_i \frac{p_T^i}{M} \delta(cos\chi - cos\theta_i)$$

Loop through the hadrons in each J/ψ event

Charged hadron p_T >0.2 GeV/c, $|\eta|$ <1

Boost the hadrons to J/ψ rest frame

* **treat all hadron as pion**

Calculate χ, the angle between the hadron and J/ψ momentum direction in J/ψ rest frame

Weight cos χ with hadron $\mathbf{p_T}$ /M as weight

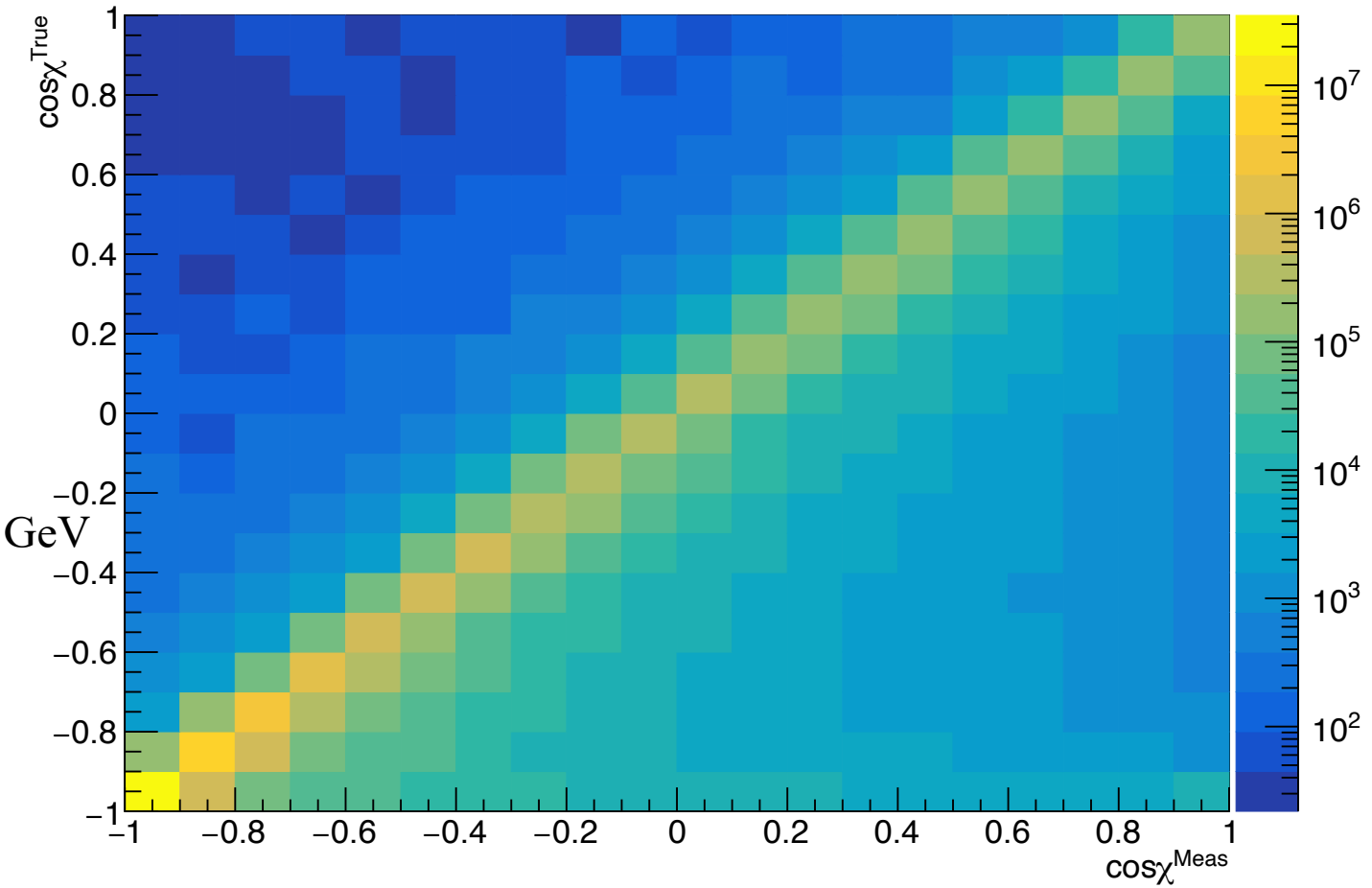
Correction: PYTHIA8 and detector response

Response matrix

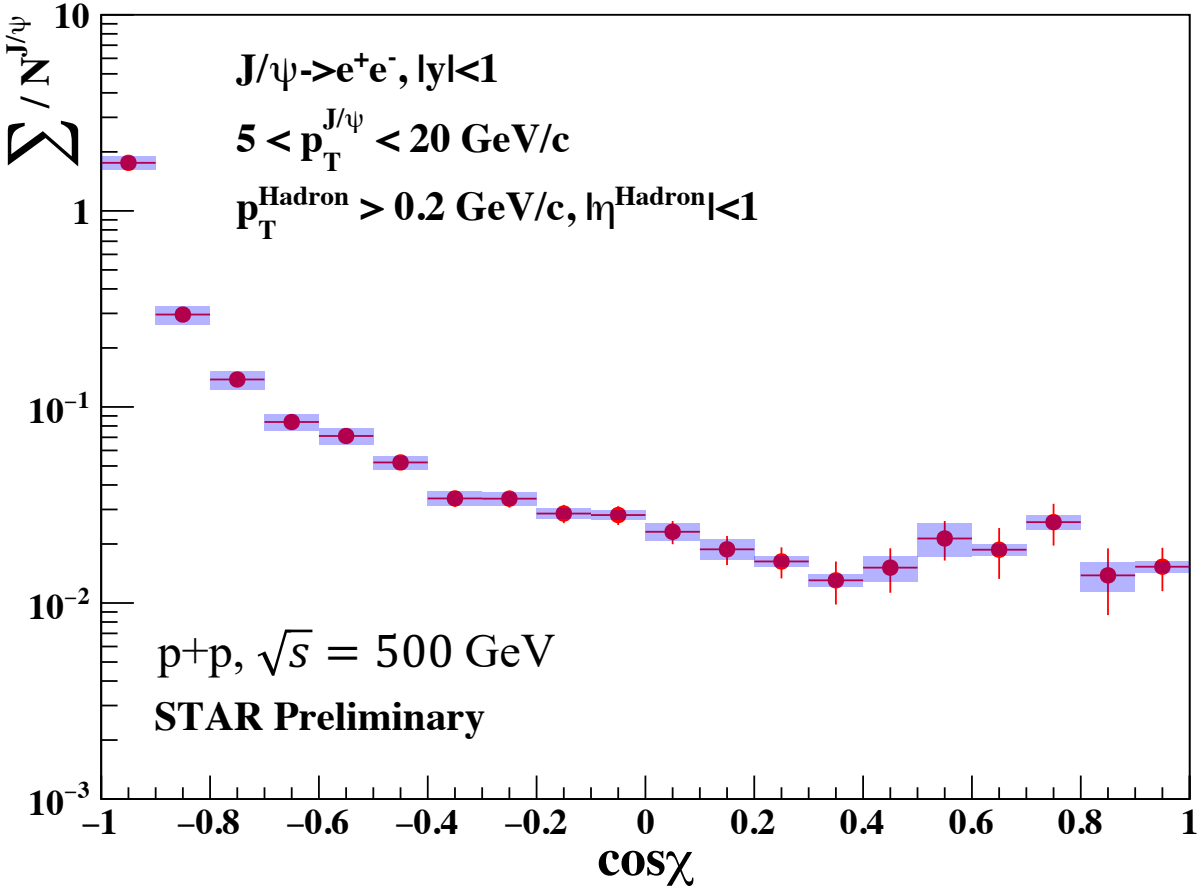
Simulations PYTHIA8 + GEANT3 in p + p $\sqrt{s} = 500$ GeV

Response Truth → Measured

p+p, $\sqrt{s} = 500$ GeV

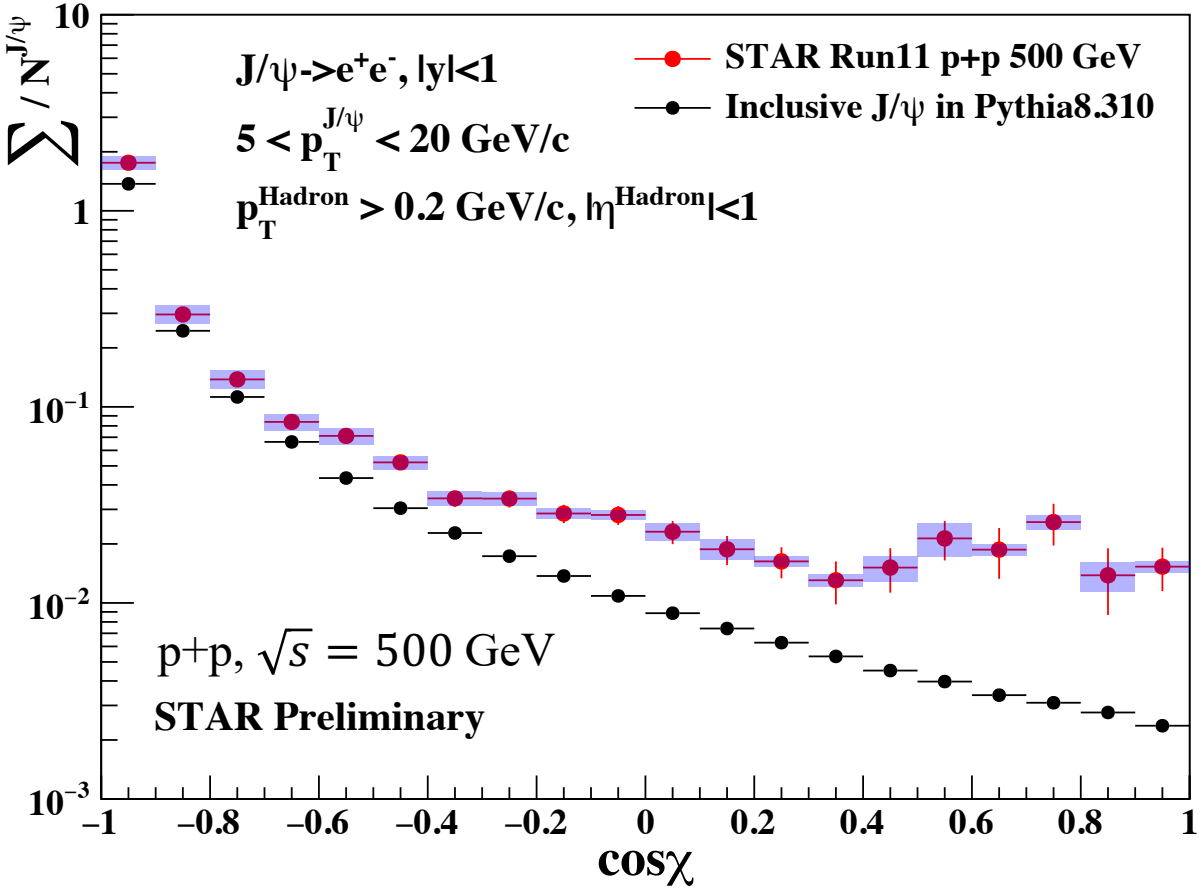


Normalized J/ψ energy correlator



- Normalized by the J/ψ yield at the mid-rapidity at $5 < p_T < 20$ GeV/c
- No significant cosχ dependence in large cosχ range

J/ψ energy correlator distribution



- No significant cosχ dependence in large cosχ range
- Significantly different J/ψ energy correlator between PYTHIA8 and data at cos$\chi > 0$ (~7σ difference)
- Studies on extracting J/ψ hadronization process's energy emission is on going

Summary

- ✓ The first J/ψ energy correlator measurement
- ✓ p+p $\sqrt{s} = 500$ GeV:
  - ➢ No significant cosχ dependence in the large cosχ range
  - ➢ Significantly different J/ψ energy correlator between PYTHIA8 and data

Outlook

- STAR data:
  - **High-statistics** p+p datasets(2017, 2022)

	2011	2017	2022
$\sqrt{s}$(GeV)	500	510	508
L_{int} (pb^{-1})	25	350	400
Pseudo-rapidity range	$\|\eta\| < 1$	$\|\eta\| < 1$	$\|\eta\| < 1$ $2.5 < \eta < 4$

This work is based on 2011 data

➢ Toward an in-depth study of J/ψ energy correlator:

1) Investigate the p_T dependence of the correlator
2) Explore J/ψ energy correlator inside jets?

Outlook

- STAR data:
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Thank you !

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