J/ψ polarization measurements in p+p collisions at √s = 200 and 500 GeV with the STAR experiment

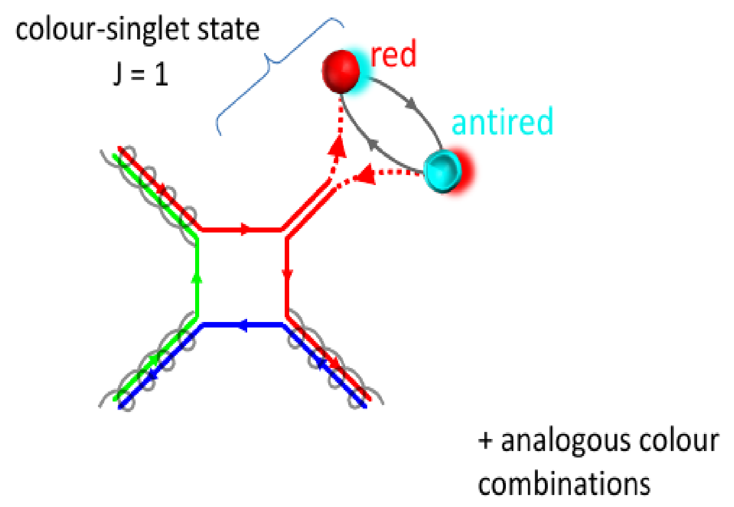
Barbara Trzeciak
for the STAR Collaboration
Faculty of Nuclear Sciences and Physical Engineering
Czech Technical University in Prague

European Physical Society
Conference on High Energy Physics 2015
22-29 July 2015
Vienna, Austria

evropský sociální fond v ČR
EVROPSKÁ UNIE
MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY
OP Vzdělávání pro konkurenceschopnost
INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

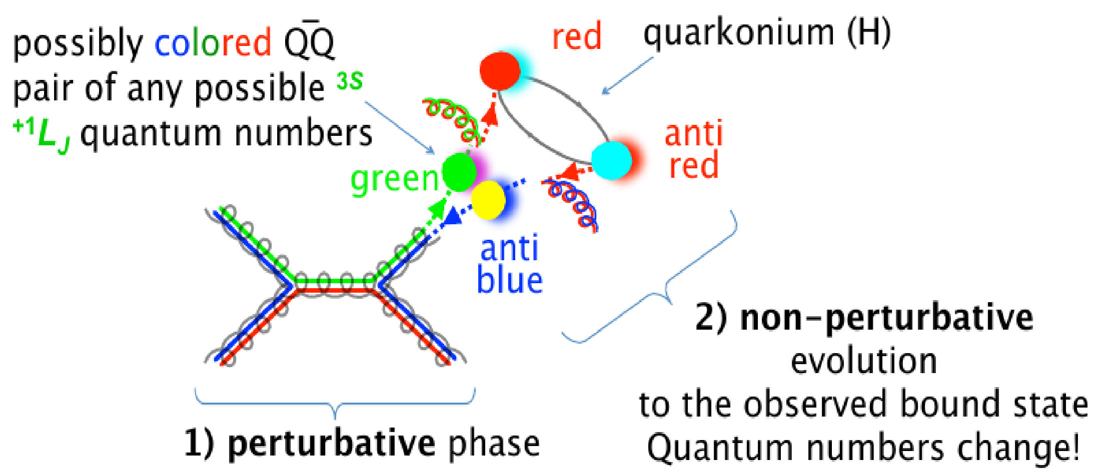
Charmonia in p+p collisions

- ***Quarkonium Production mechanism*** in elementary collisions is not fully understood
  - ➔ Color singlet vs color octet intermediate state



- ***Different models on the market:***
  - ✓ Color Singlet Model
  - ✓ Color Evaporation Model – *no prediction for the polarization*
  - ✓ NRQCD approach – *applicable at high p_T*
  - ✓ CGC+NRQCD – *applicable at low p_T*

  ➔ ***Quarkonium measurements - tests of different production models, help to understand QCD***



- ***Feed-down***

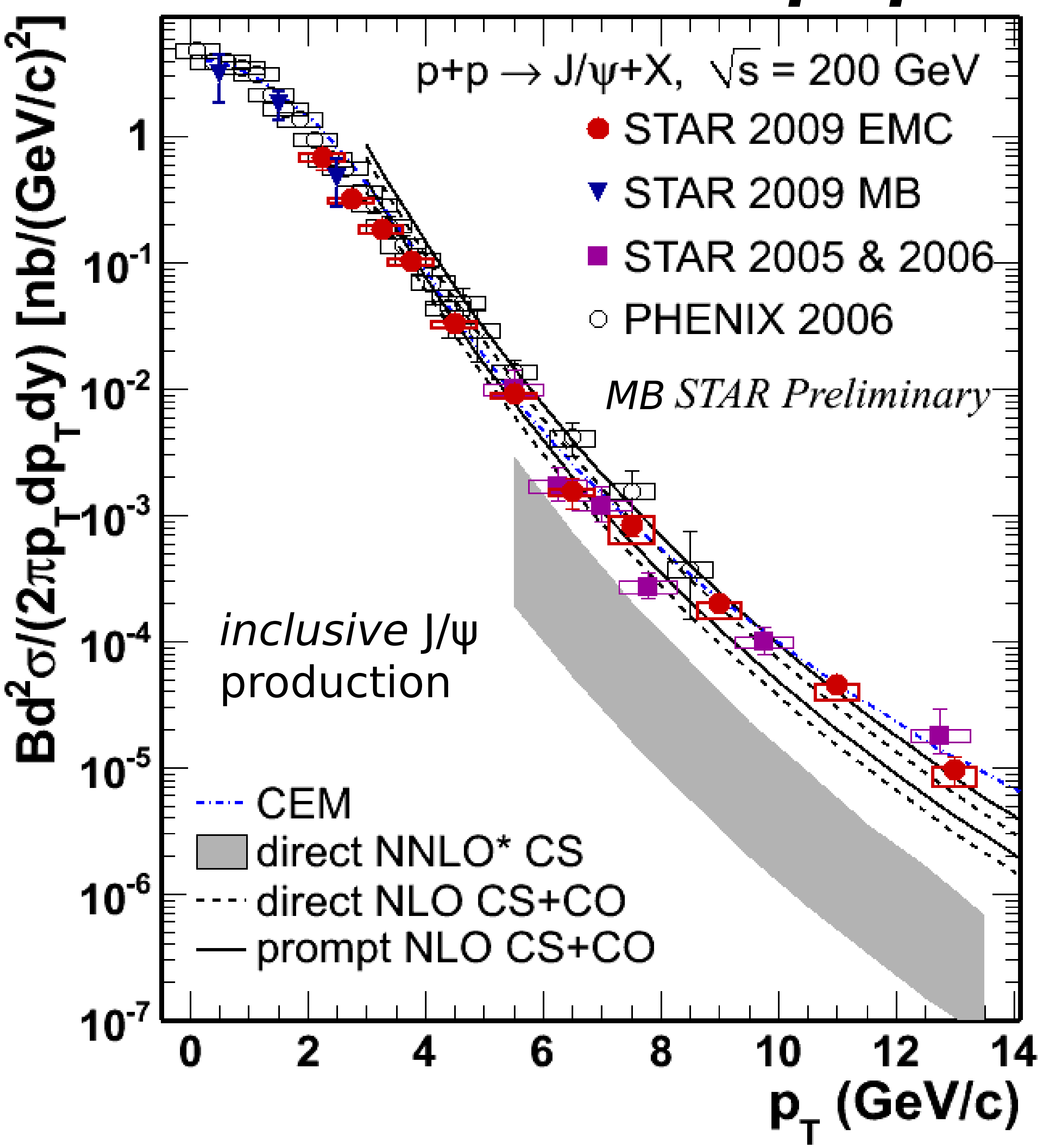
  Inclusive J/ψ production:
  - <u>prompt J/ψ</u>
    - direct J/ψ (~60%), feed down from ψ(2S) (~10%) and χ_C (~30%) decays
  - <u>non-prompt J/ψ</u>: B-mesons feed-down (10-25% at 4-12 GeV/c, STAR: Phys. Lett. B722 (2013) 55)

J/Ψ p_T spectrum

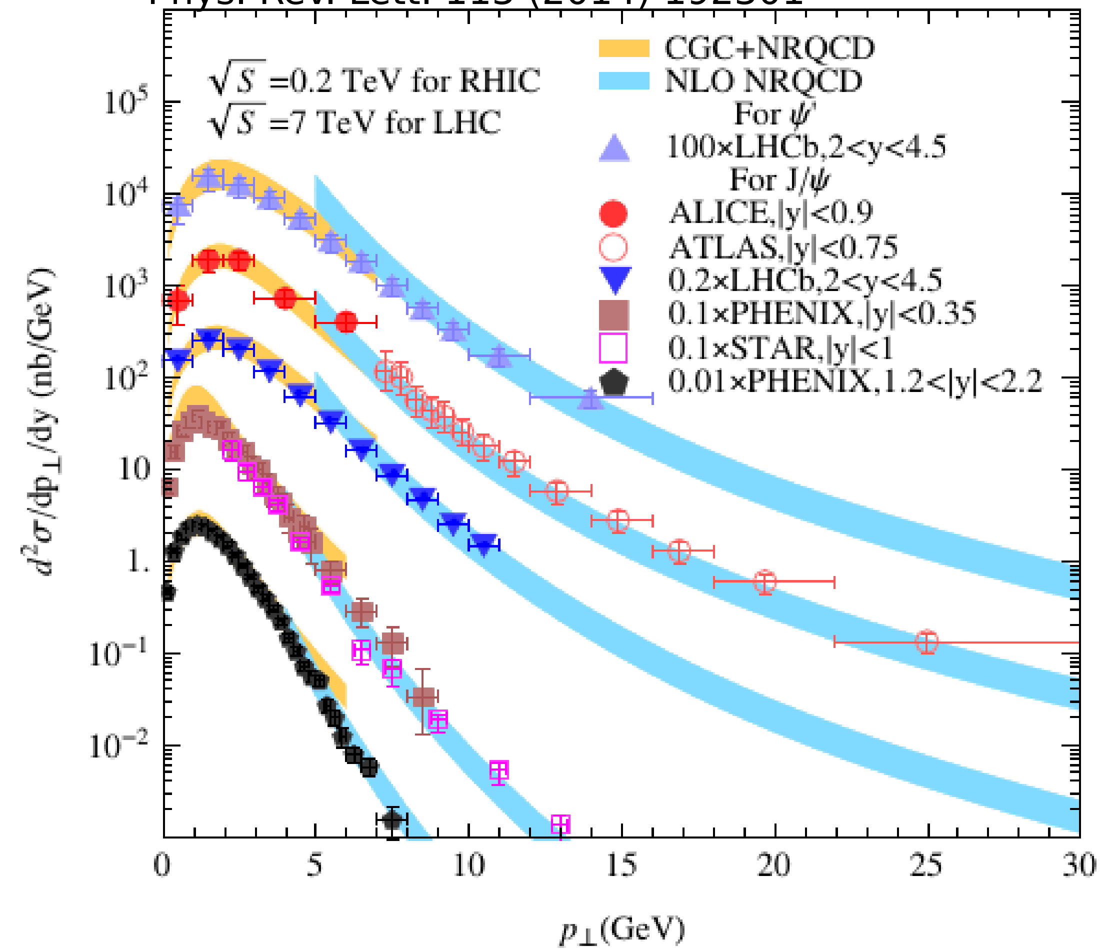
- Test of different production models

p+p 200 GeV

STAR 2005&2006: Phys. Rev. C80, 041902(R) (2009)
PHENIX: Phys. Rev. D 85, 092004 (2012)
direct NNLO CS: P.Artoisenet et al., Phys. Rev. Lett. 101, 152001 (2008) and J.P.Lansberg private communication
NLO CS+CO: Y.-Q.Ma, K.Wang, and K.T.Chao, Phys. Rev. D 84, 51 114001 (2011) and private commnication
CEM: A.D. Frawley, T Ullrich, R. Vogt, Phys. Rept. 462 (2008) 125, and R.Vogt private communication



Phys. Rev. Lett. 113 (2014) 192301



✓ **Different models can reasonably well describe measured cross-sections**

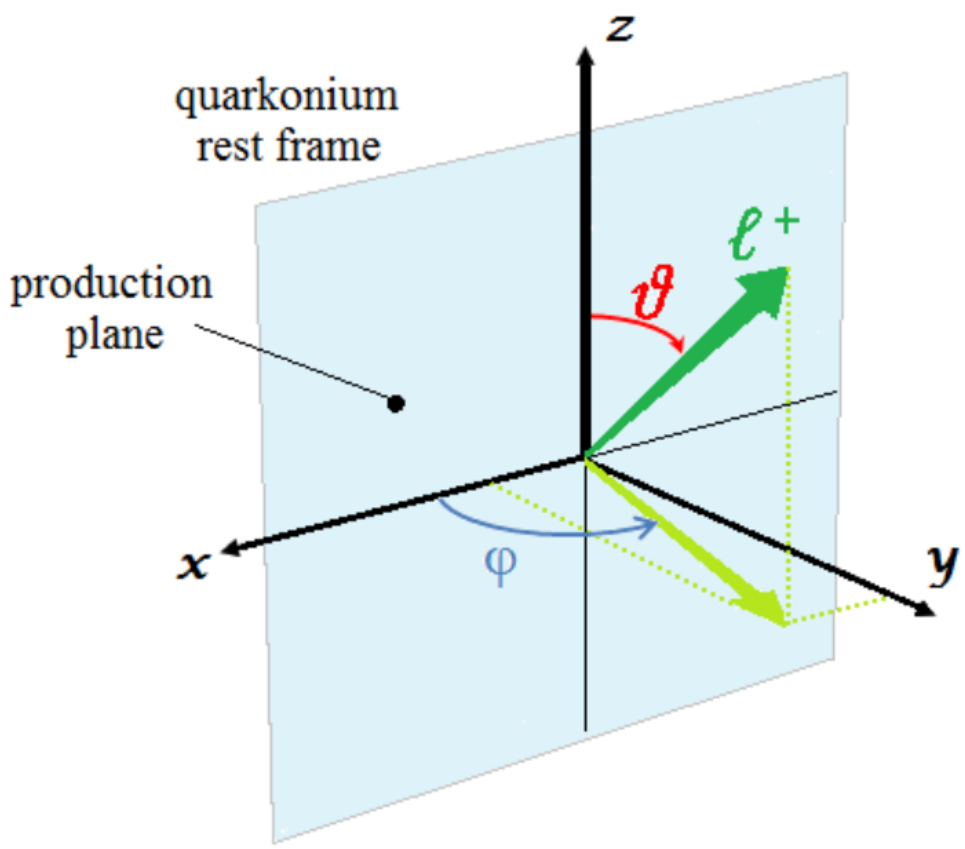
STAR EMC : Phys. Lett. B 722 (2013) 55
STAR MB: Acta Phys. Polonica B Vol.5, No 2 (2012), 543

J/Ψ polarization

- Further constraints for J/ψ production models
  - ➔ Different production mechanisms in competing theoretical approaches lead to different expected polarization

J/ψ polarization can be analyzed via the angular distribution of the decay lepton pair

$$\frac{d\sigma}{d(cos\theta)d\phi} \propto 1 + \lambda_\theta cos^2\theta + \lambda_{\theta\phi} sin(2\theta)cos\phi + \lambda_\phi sin^2\theta cos(2\phi)$$



- ✔ **θ** - polar angle between momentum of a positive lepton in the J/ψ rest frame and the polarization axis *z*
- ✔ **φ** - corresponding azimuthal angle

Polarization z axis:

- ***Helicity (HX) frame***: along the J/ψ momentum in the center of mass frame
- ***Collins-Soper (CS) frame***: bisector of the angle formed by one beam direction and the opposite direction of the other beam in the J/ψ rest frame

Polarization parameters

- The angular distribution, integrated over

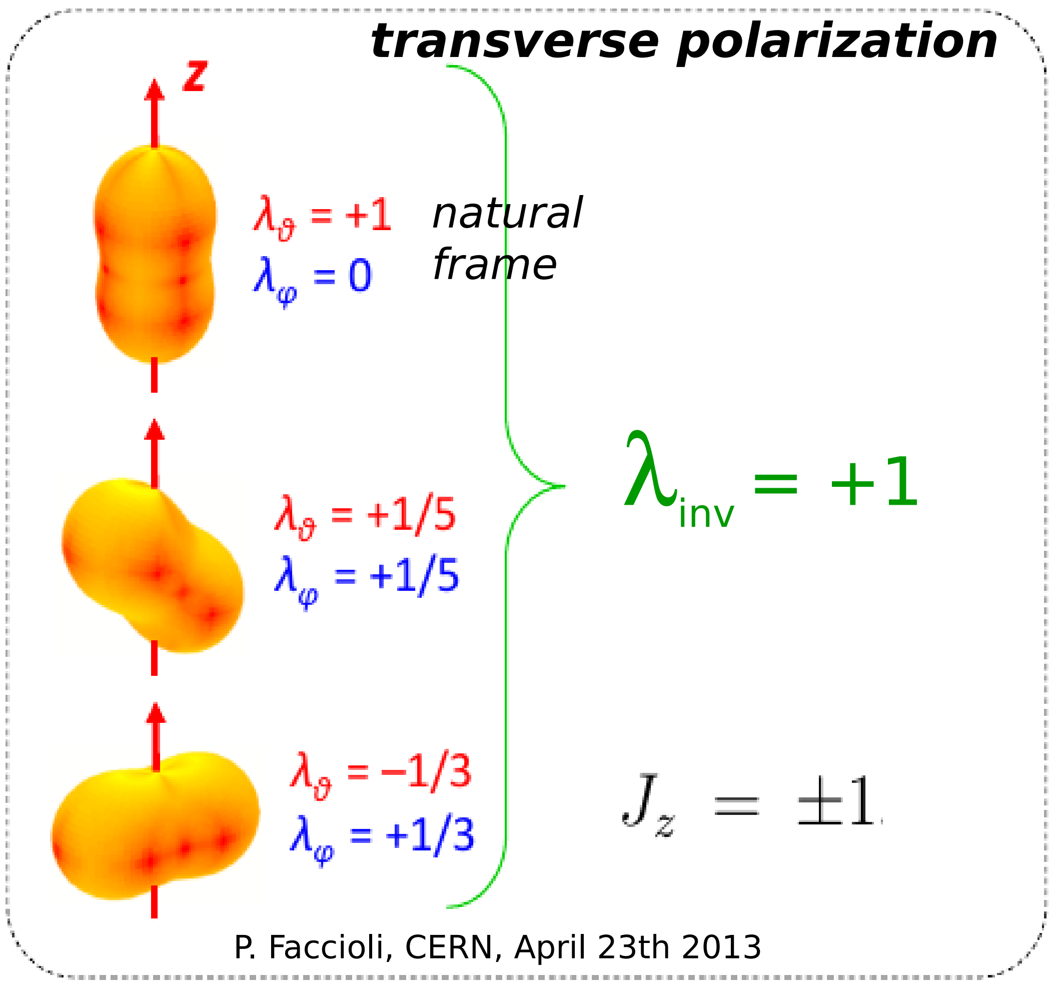
azimuthal angle:

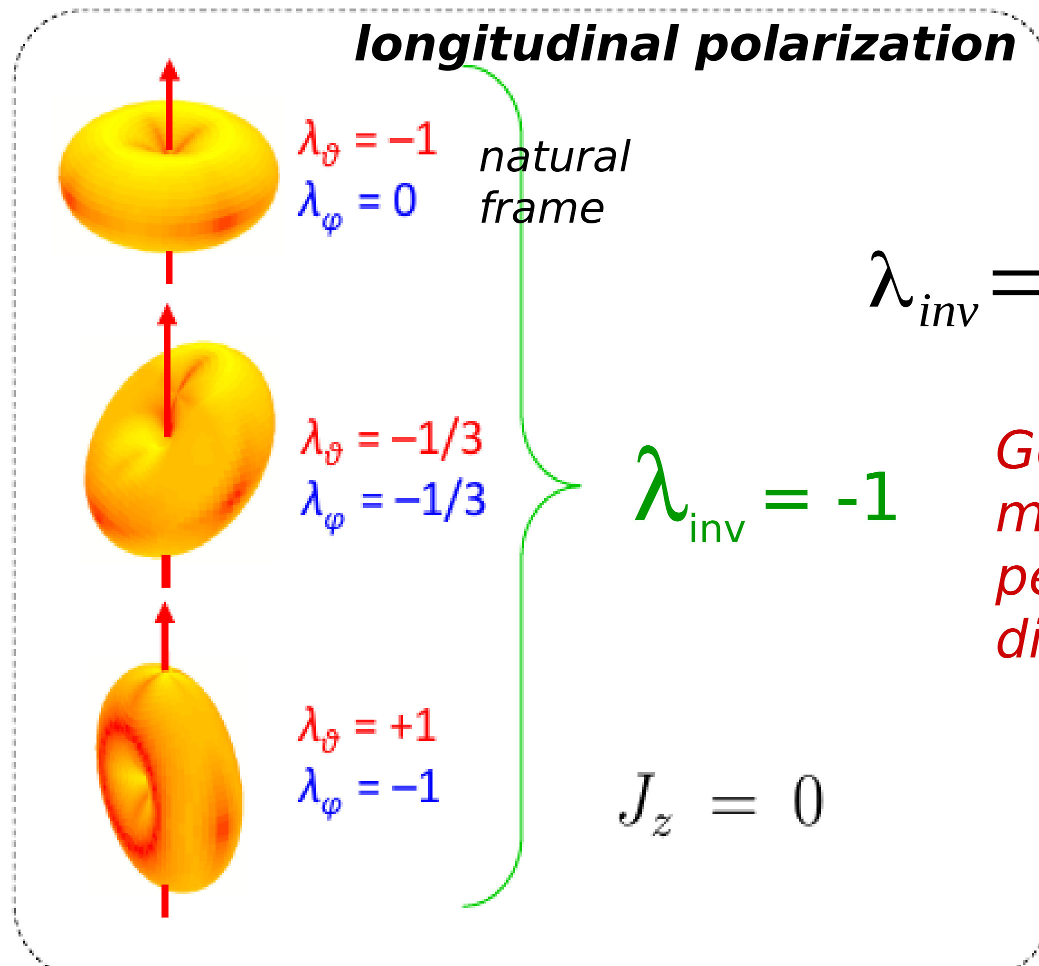
$$W(\cos\theta) \propto 1 + \lambda_\theta \cos^2\theta$$

polar angle:

$$W(\varphi) \propto 1 + \frac{2\lambda_\varphi}{3+\lambda_\theta}\cos 2\varphi$$

- Frame invariant quantity:





$$\lambda_{inv} = \frac{\lambda_\theta + 3\lambda_\varphi}{1 - \lambda_\varphi}$$

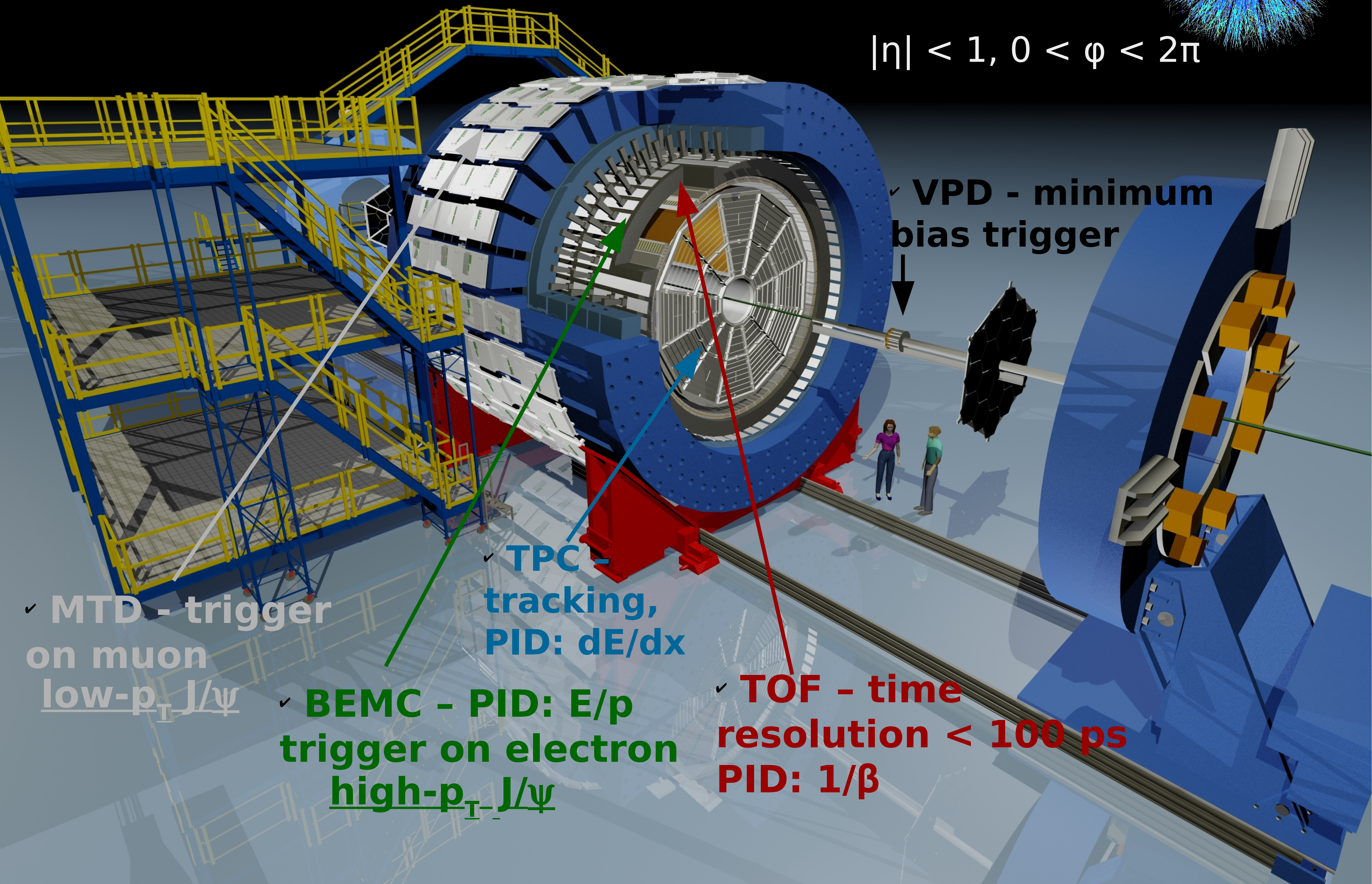
Good cross-check of measurements performed in different frames

Any arbitrary choice of the experimental observation frame will give the same value of this quantity

P. Faccioli, et al., Eur. Phys. J. C 69, 657 (2010)

Quarkonia in the STAR Experiment

$J/\psi \,/\, \Upsilon \rightarrow e^{+} e^{-} , \mu^{+} \mu^{-}$

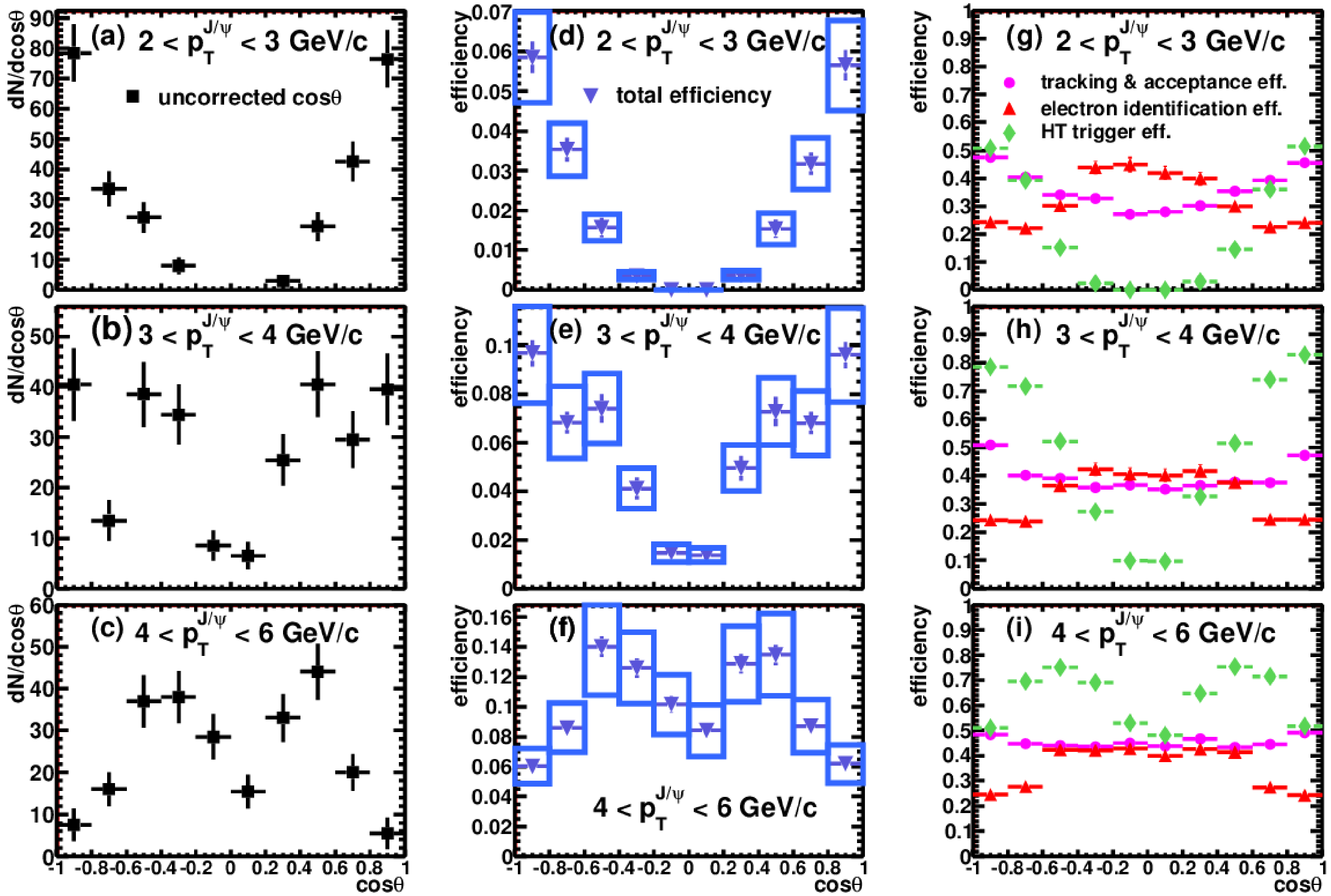


J/Ψ polarization in p+p 200 GeV

- **First J/ψ polarization measurement at STAR, in the HX frame**

Uncorrected cosθ distributions and different efficiency components

- $|y| < 1$, $2 < p_T < 6$ GeV/c



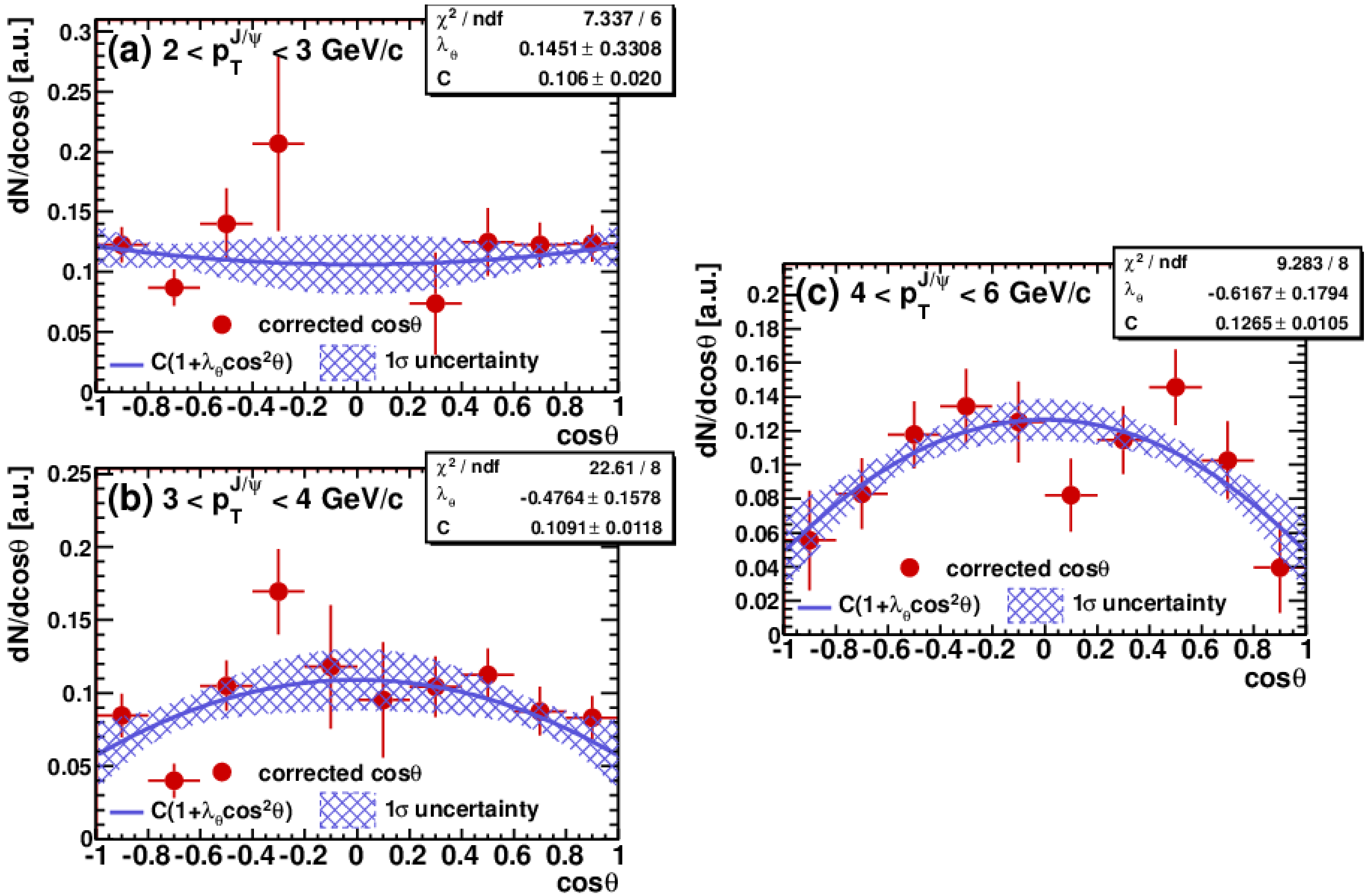
Phys.Lett. B739 (2014) 180

J/Ψ polarization in p+p 200 GeV (2)

Corrected cosθ distributions

- λ_θ parameter measured by fitting angular distribution integrated over ϕ angle:

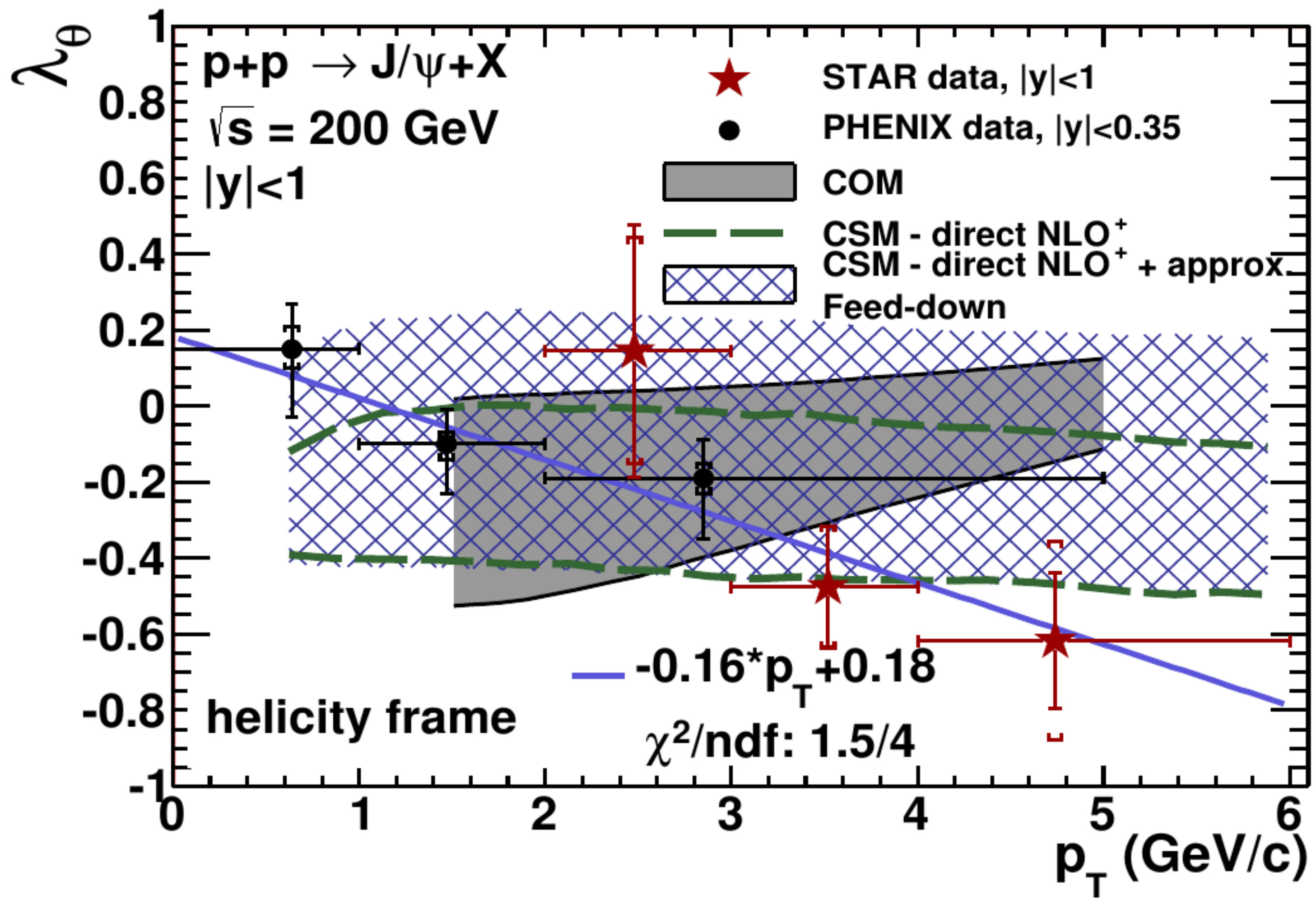
$$W(\cos\theta) \propto 1 + \lambda_\theta \cos^2\theta$$



Phys.Lett. B739 (2014) 180

λ_θ vs p_T at 200 GeV in HX frame

PHENIX: Phys. Rev. D 82, 012001 (2010)
COM: Phys. Rev. D 81, 014020 (2010)
CSM NLO⁺: Phys. Lett. B, 695, 149 (2011)
and private communication

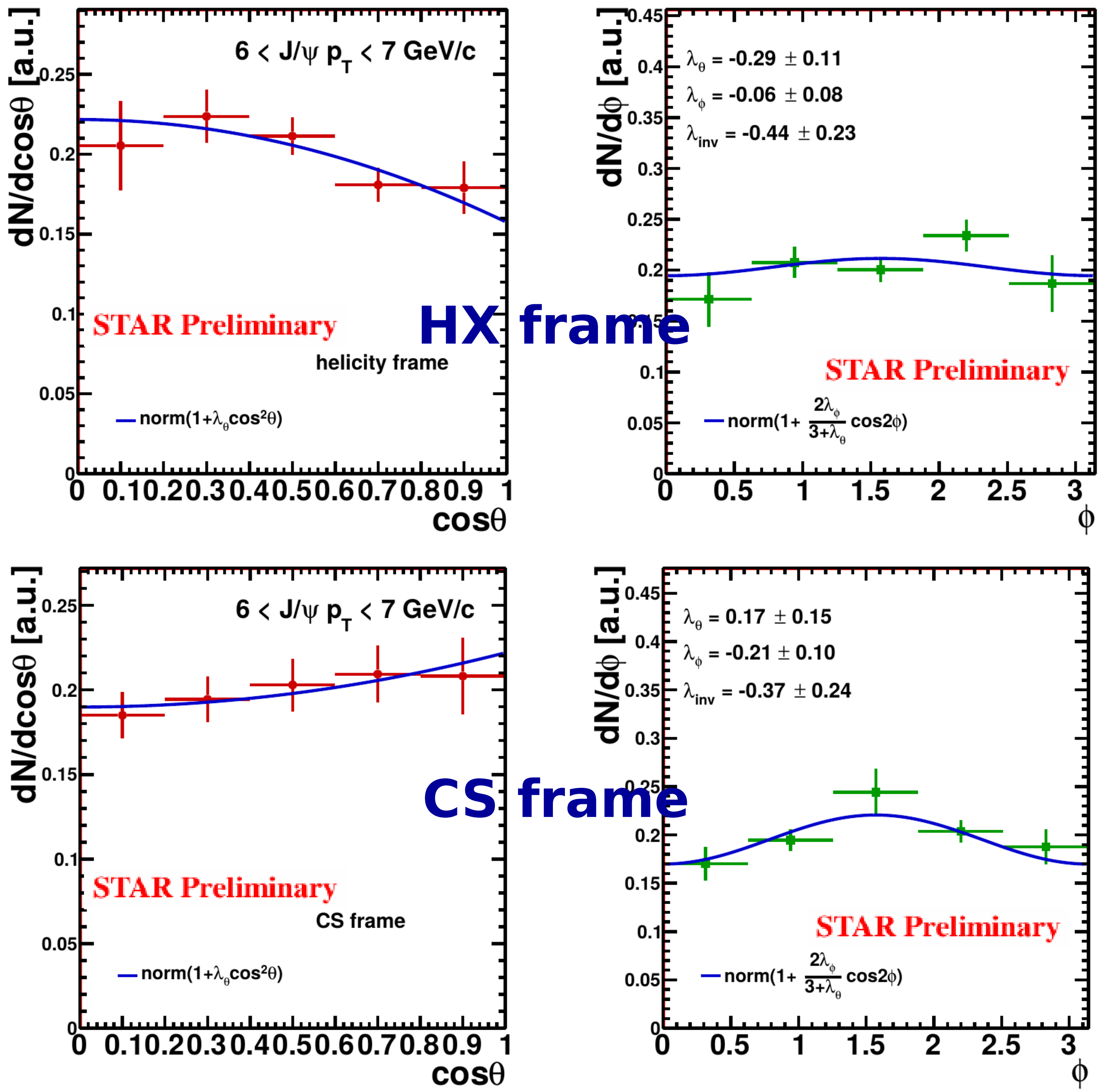


Phys.Lett. B739 (2014) 180

- RHIC data indicate trend towards longitudinal polarization with increasing p_T
- The result is consistent with NLO⁺ CSM

J/Ψ polarization in p+p 500 GeV

- **Extending J/ψ polarization measurement at STAR to the azimuthal angle φ and the CS frame**



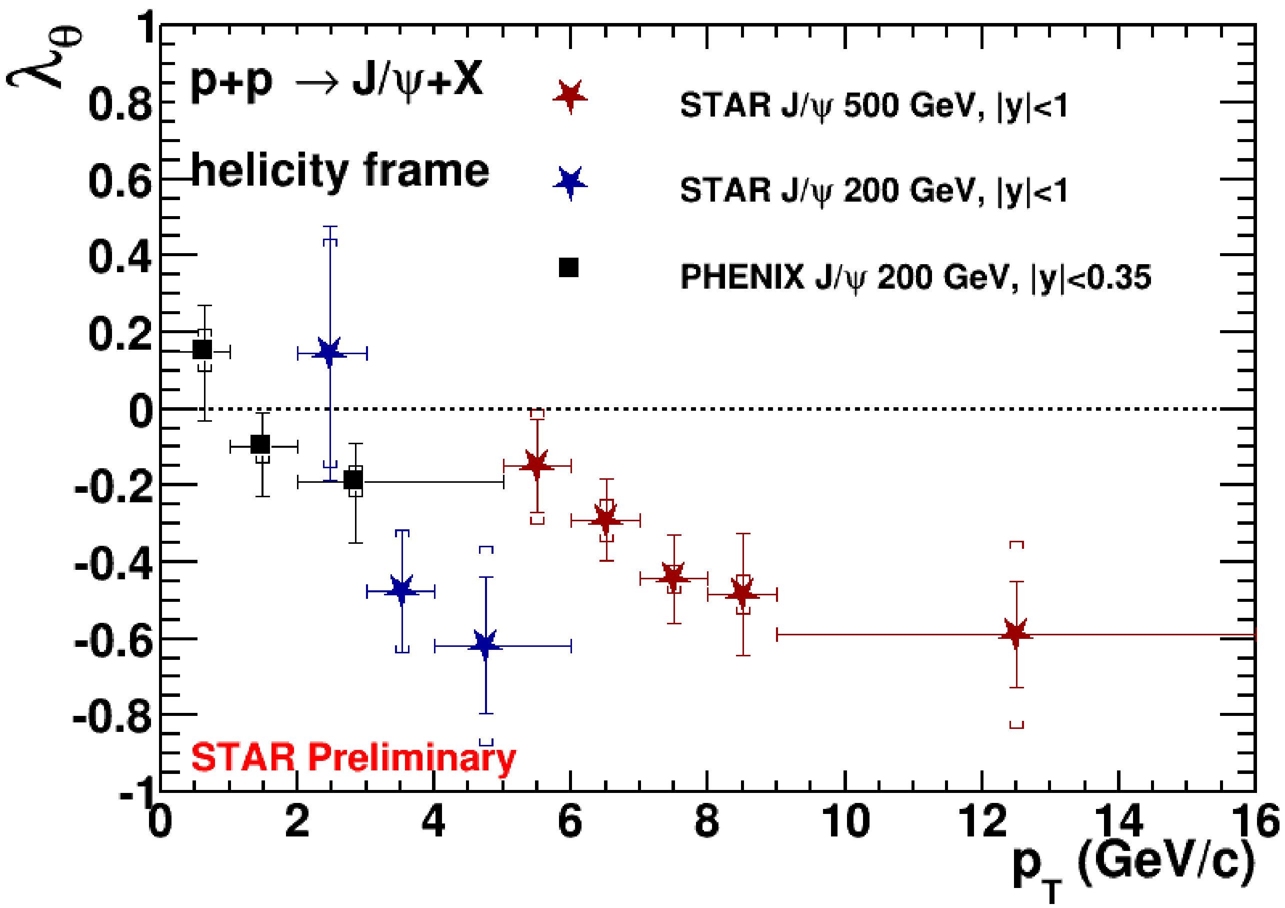
- Simultaneous fit to cosθ and ϕ distributions
- Angular distribution integrated over ϕ and θ angles, respectively:

$$W(\cos\theta) \propto 1 + \lambda_\theta \cos^2\theta$$

$$W(\varphi) \propto 1 + \frac{2\lambda_\varphi}{3+\lambda_\theta}\cos 2\varphi$$

λ_θ vs p_T at 500 GeV in HX frame

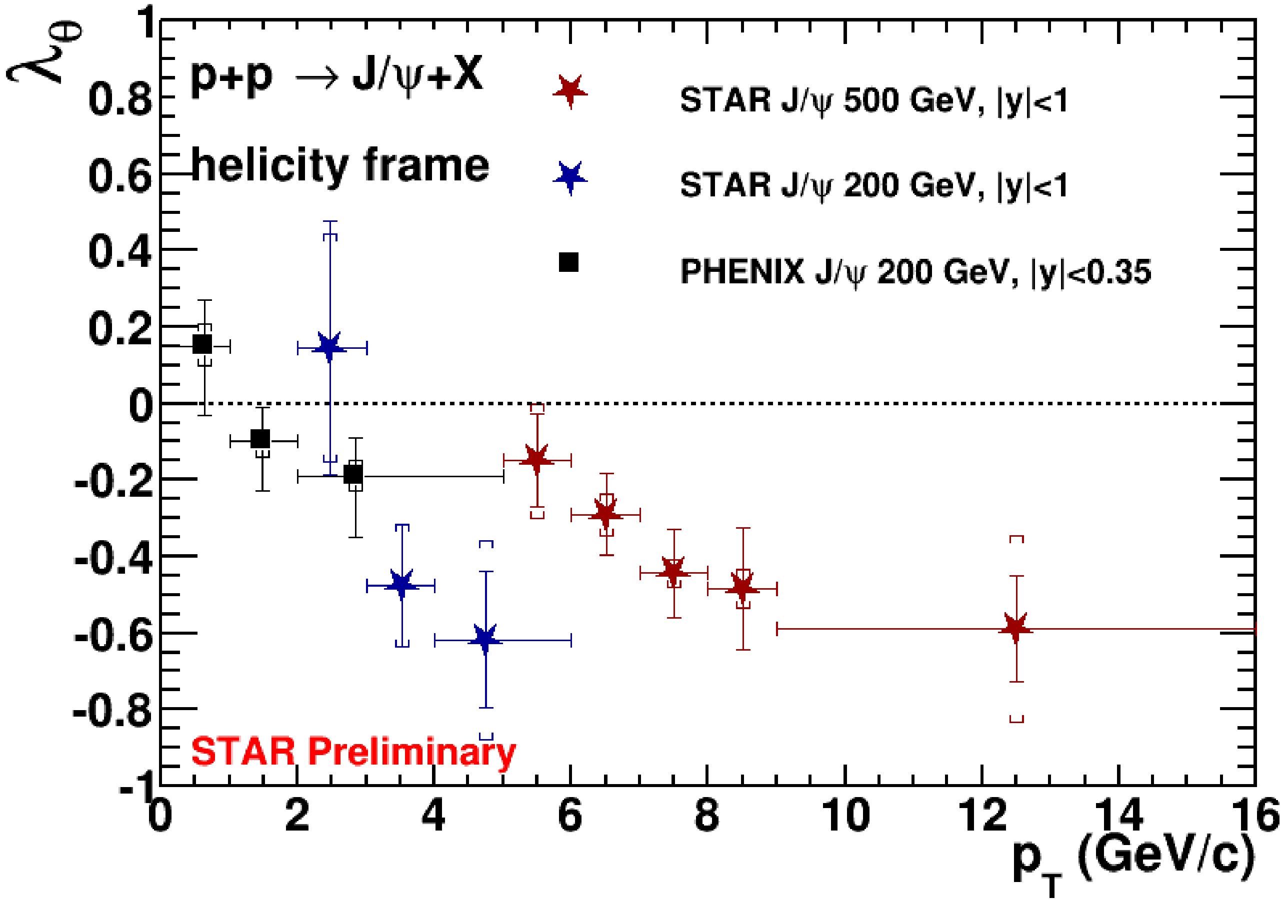
λ_θ parameter in HX frame



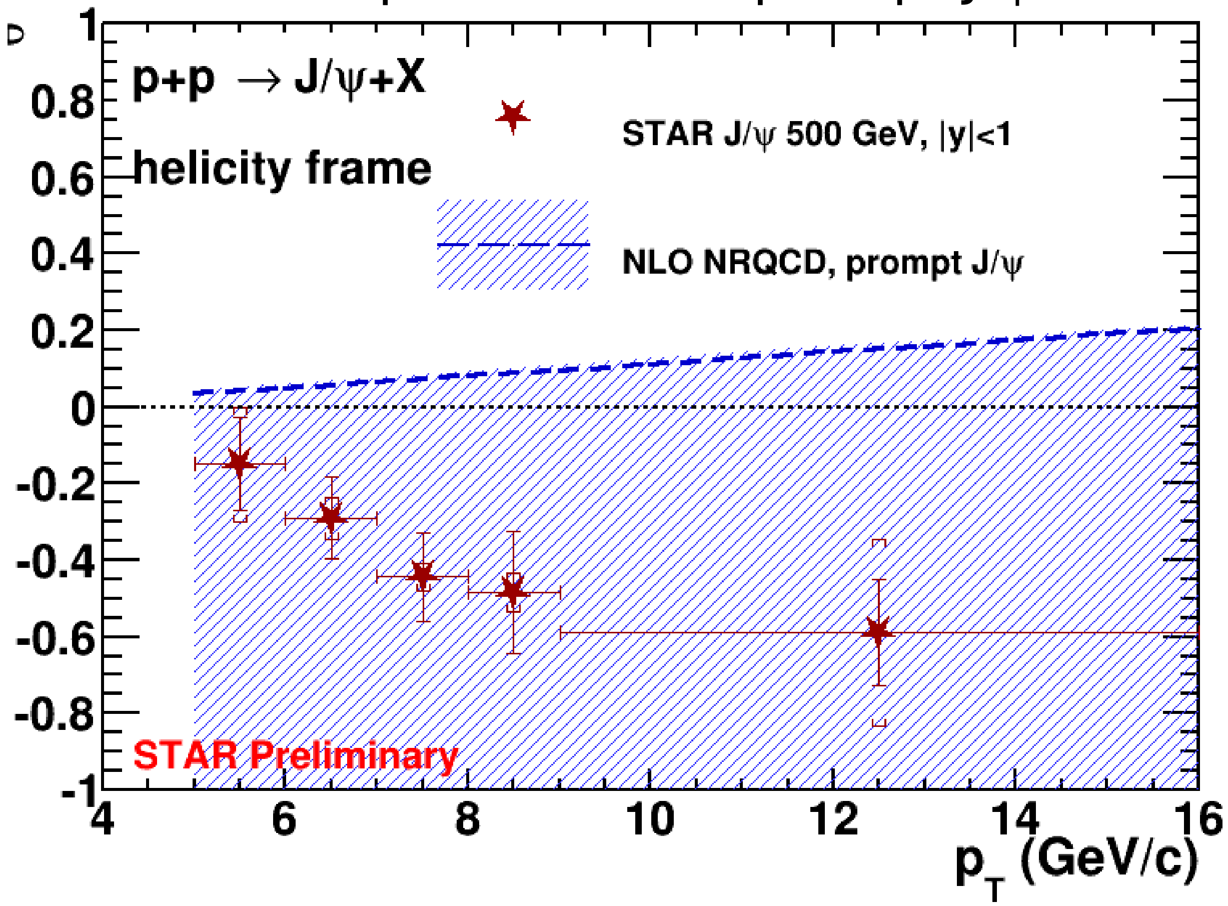
- Similar trend observed in 500 and 200 GeV p+p collisions
- Measurement extended to higher p_T range, $5 < p_T < 16$ GeV/c

λ_θ vs p_T at 500 GeV in HX frame

λ_θ parameter in HX frame



data vs NLO NRQCD prediction for prompt J/ψ

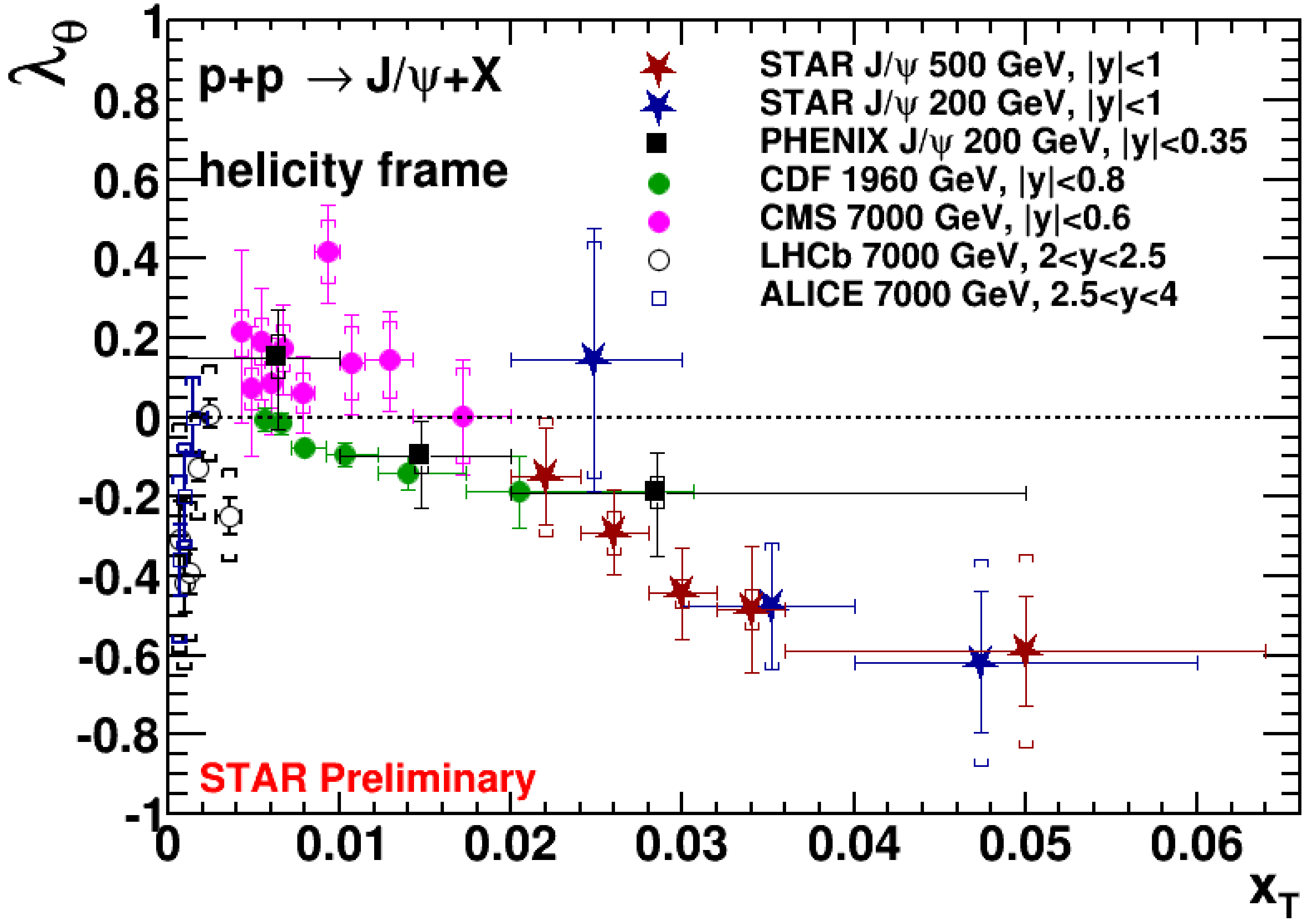


- Similar trend observed in 500 and 200 GeV p+p collisions
- Measurement extended to higher p_T range, $5 < p_T < 16$ GeV/c
- Data can help to constrain color-octet Long-Distance Matrix Elements

NLO NRQCD:
Phys. Rev. Lett. 108 (2012) 242004, Phys.Rev. D90 (2014) 1, 014002, Phys.Rev.Lett 112 (2014) 18, JHEP 1505 (2015) 103
And private communication

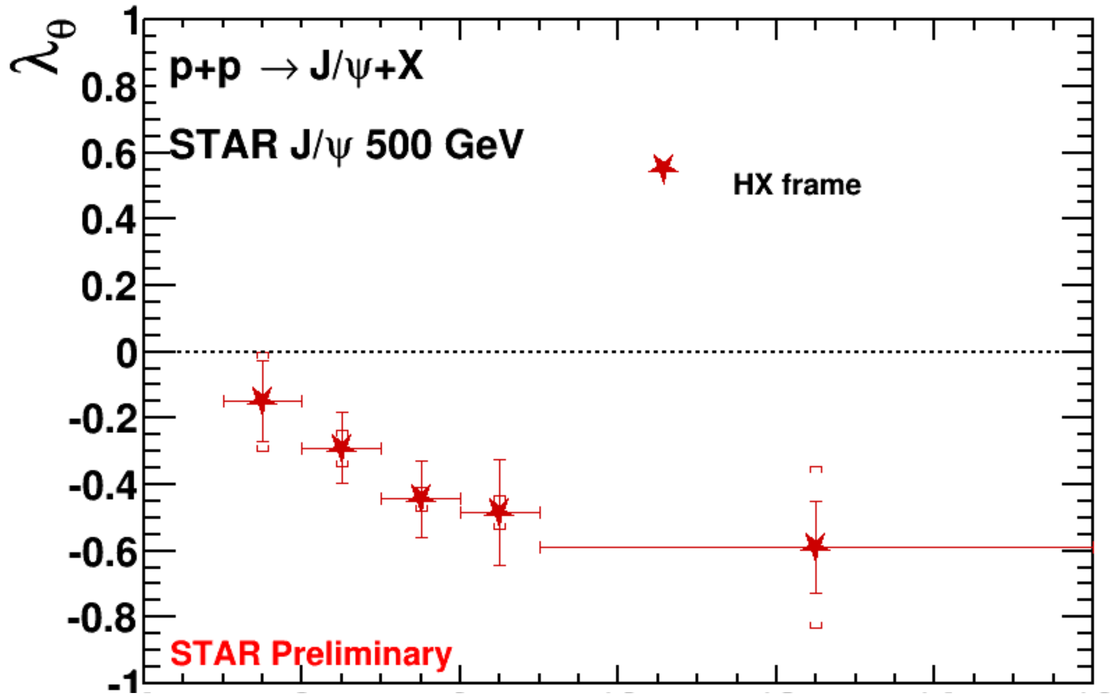
x_T dependence of λ_θ in the HX frame

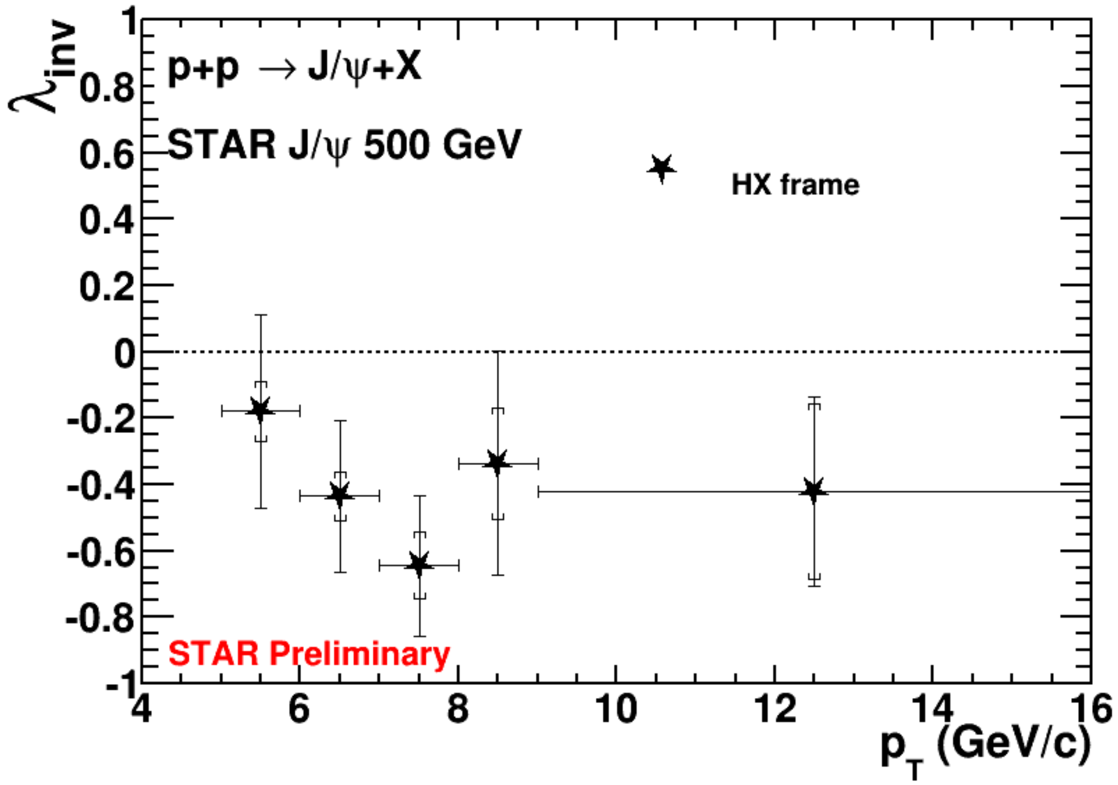
$$x_T = 2p_T/\sqrt{s}$$

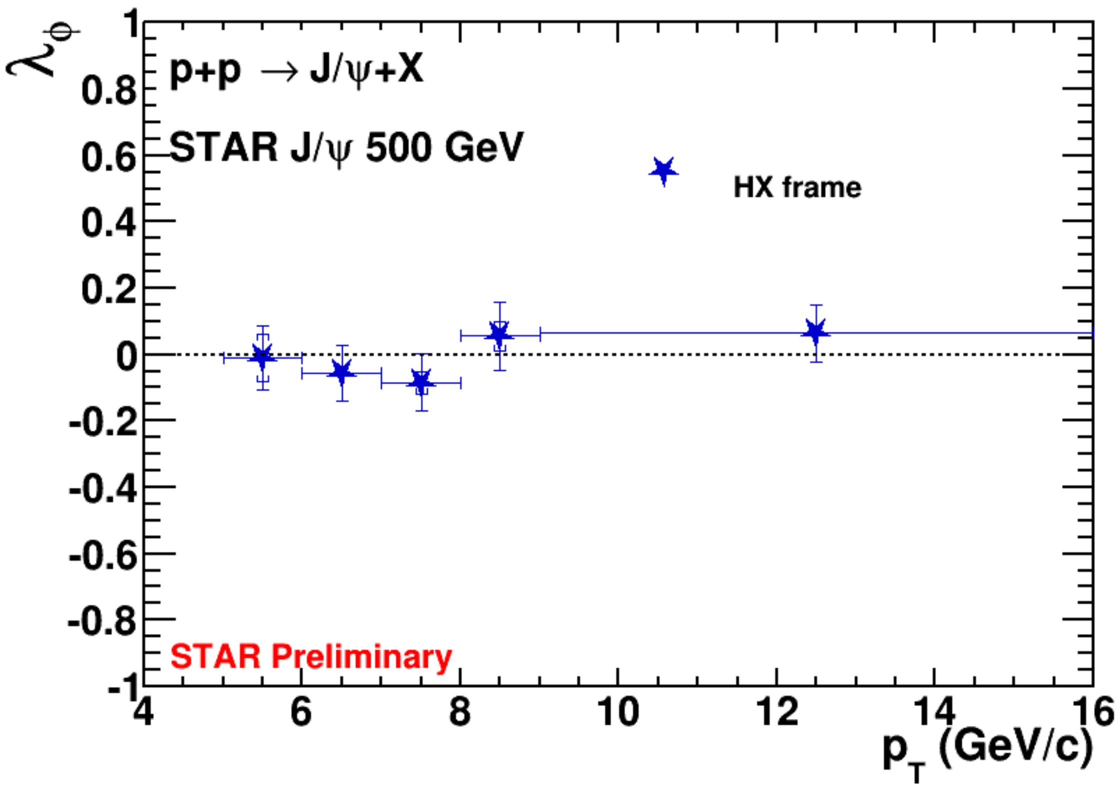


- Common trend towards strong negative values with increasing x_T

λ_φ and λ_{inv} parameters at 500 GeV, HX frame

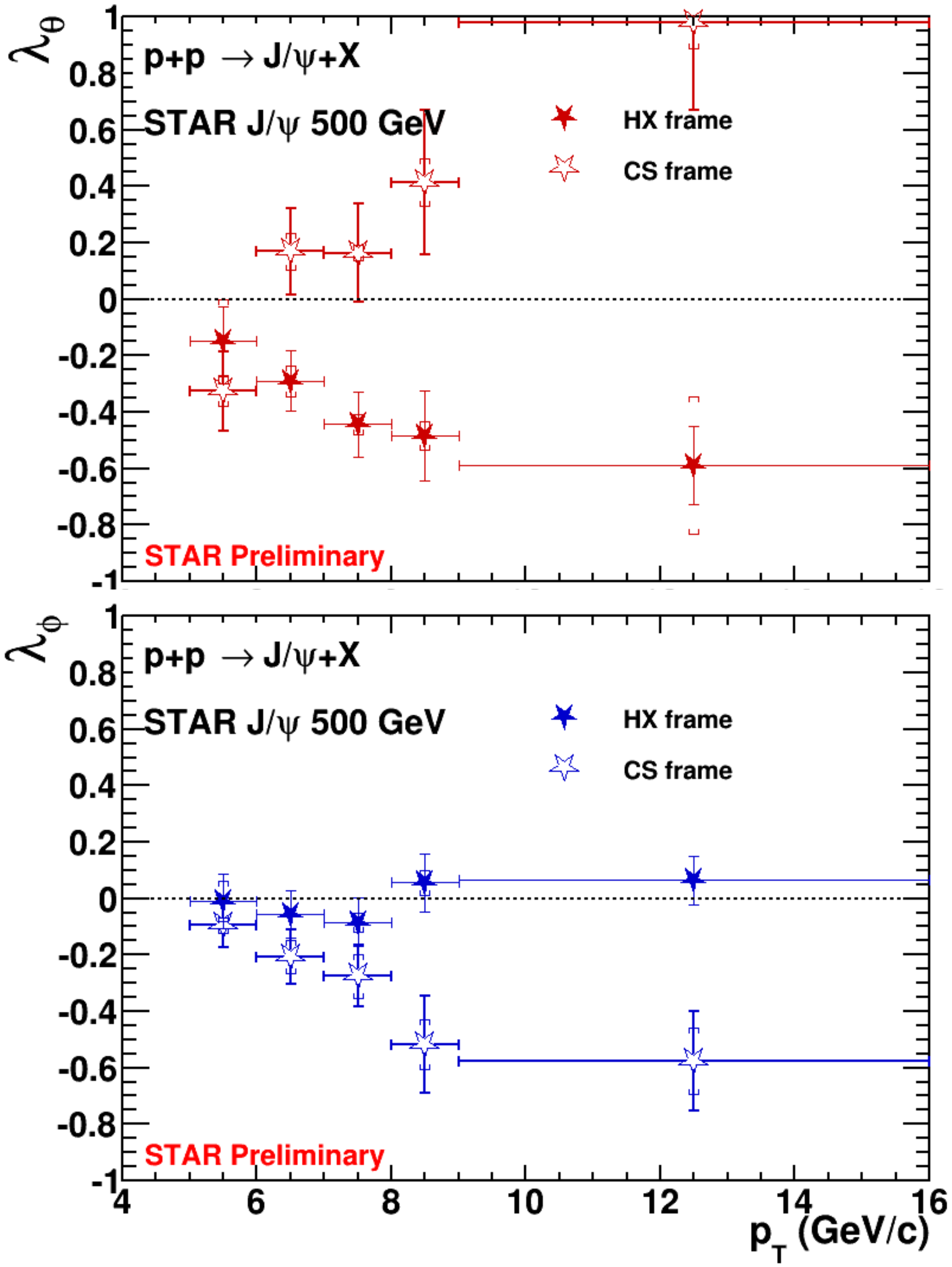


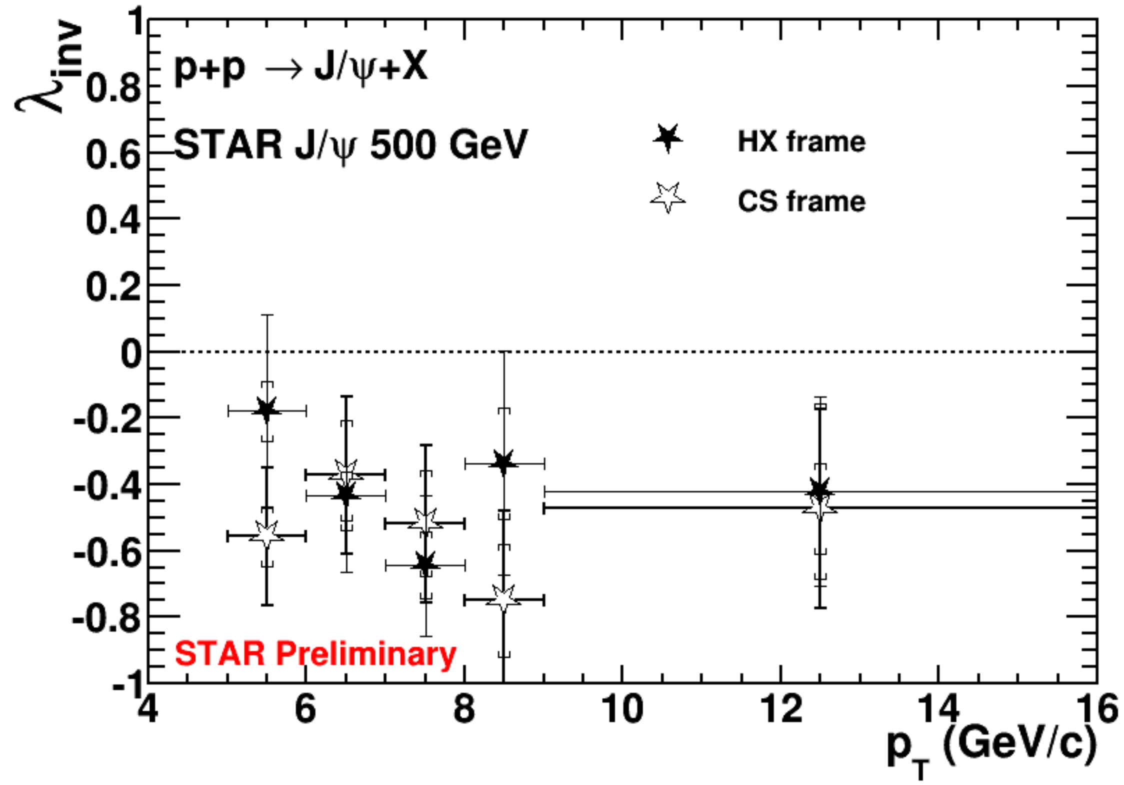




- No strong azimuthal anisotropy observed in the HX frame
- Negative values of the frame invariant λ_{inv} parameter
- Trend towards longitudinal polarization with increasing p_T

J/Ψ polarization, HX vs CS frame





- Different values of the λ_θ and λ_ϕ polarization parameters in the CS frame
- Frame invariant parameters, λ_{inv}, consistent in both frames

Summary

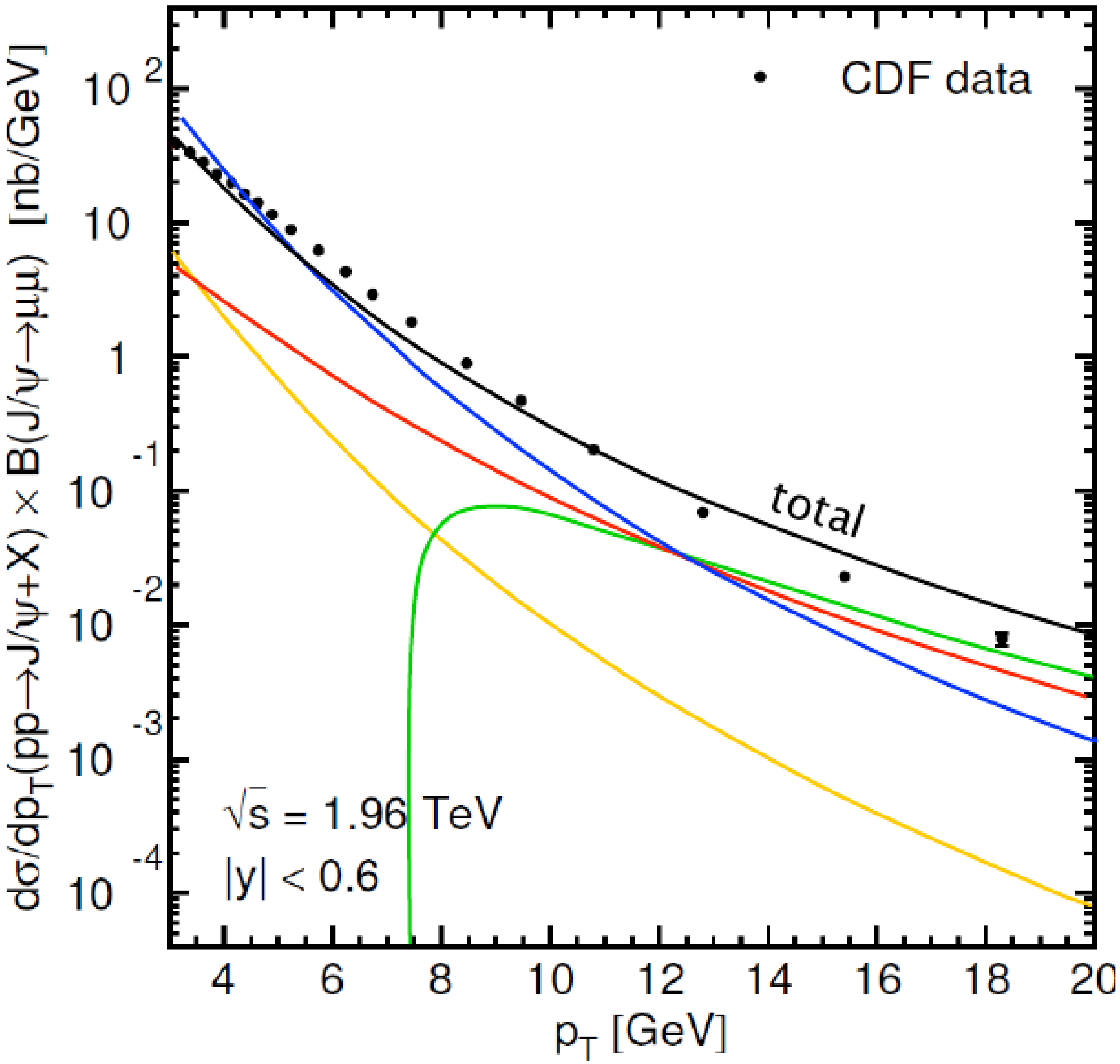
- Longitudinal J/ψ polarization in HX frame at $\sqrt{s}$ = 200 and 500 GeV
  - No strong azimuthal anisotropy observed
    - HX frame seems to be the "natural frame"
  - x_T dependence of λ_θ observed
- Different values of the λ_θ and λ_ϕ polarization parameters in CS frame
- Frame invariant parameters agree in both frames

Czech Technical University in Prague
Faculty of Nuclear Science and Physical Engineering
Project „ Support of inter-sectoral mobility and quality enhancement of research teams at Czech Technical University in Prague "
CZ.1.07/2.3.00/30.0034

Thank you !

J/Ψ production mechanism - NRQCD

Each color singlet and octet term has a specific polarization associated



C. Lourenço et al., Hard Probes 2013

colour-singlet $^3S_1$

$\lambda_\theta = +1$ at LO to $\lambda_\theta = -1$ at NLO

tiny fraction of the total cross section

octet $^1S_0$ → $\lambda_\theta = 0$ at LO, NLO

octet $^3S_1$ → $\lambda_\theta = +1$ at LO, NLO, at high p_T

octet ^3P_J → $\lambda_\theta >> +1$ at NLO at LO it is 0

Dominance of the $^3S_1$ and ^3P_J octet terms

→ $\lambda_\theta \approx +1$,

for high-p_T S-wave quarkonia

Color-octet contributions have fixed shape but adjustable normalizations (LDMEs)