A recent paper on FT quarkonium polarization

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Low-p_T quarkonium polarization measurements: Challenges and opportunities

Pietro Faccioli [a,*], Ilse Krätschmer [b], Carlos Lourenço [c]

[a] *LIP, Lisbon, Portugal*
[b] *ISTA, Klosterneuburg, Austria*
[c] *CERN, Geneva, Switzerland*

Stephane Platchkov

Paris-Saclay University, CEA/IRFU, France

Measurements considered: J/psi

“In this paper we devote our attention to low-p_T quarkonium hadro-production, a kinematical domain complementary to that explored in collider experiments.”

- Consider all FT quarkonia polarization data
  - Data in three different frames
  - Different particles (p, $\pi+$, $\pi-$, $\bar{p}$) and energies
    - sqrt(s) from 15.3 to 41.6 GeV
  - Absence of acceptance correlation between $\cos\theta$ and φ
  - Most polarization values for J/psi are near 0

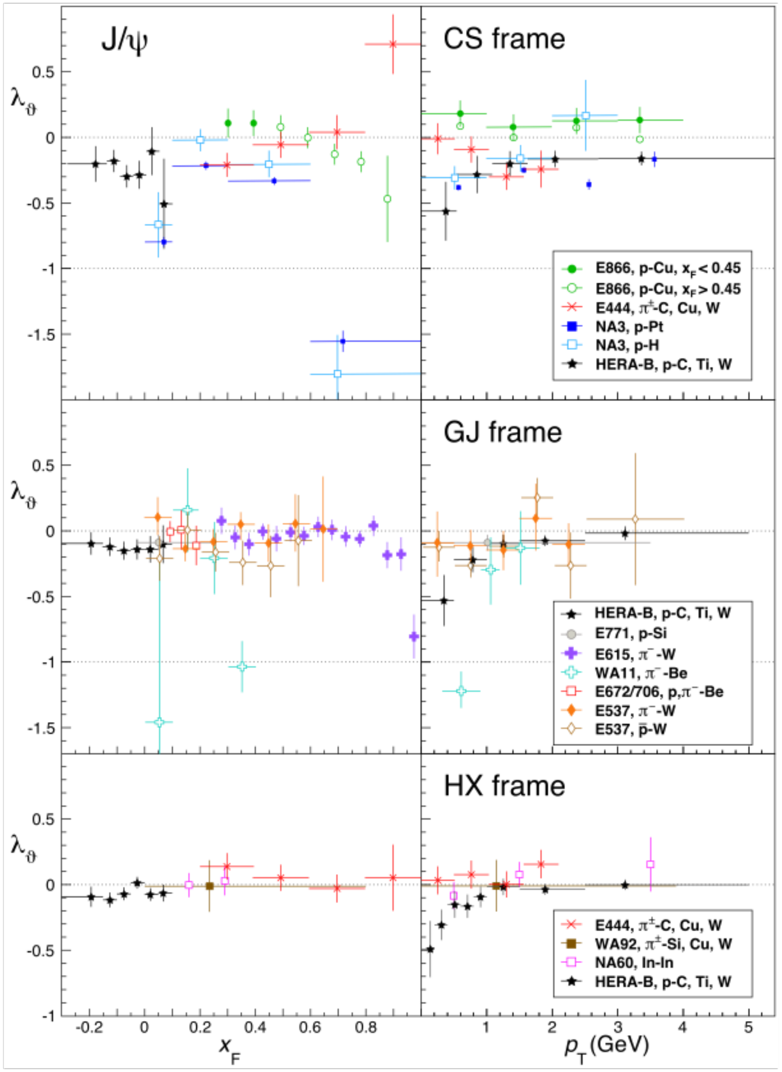


Fig. 1. The J/ψ polar anisotropy parameter λ_ϑ measured in the CS, GJ, and HX frames (top to bottom), vs. x_F and p_T.

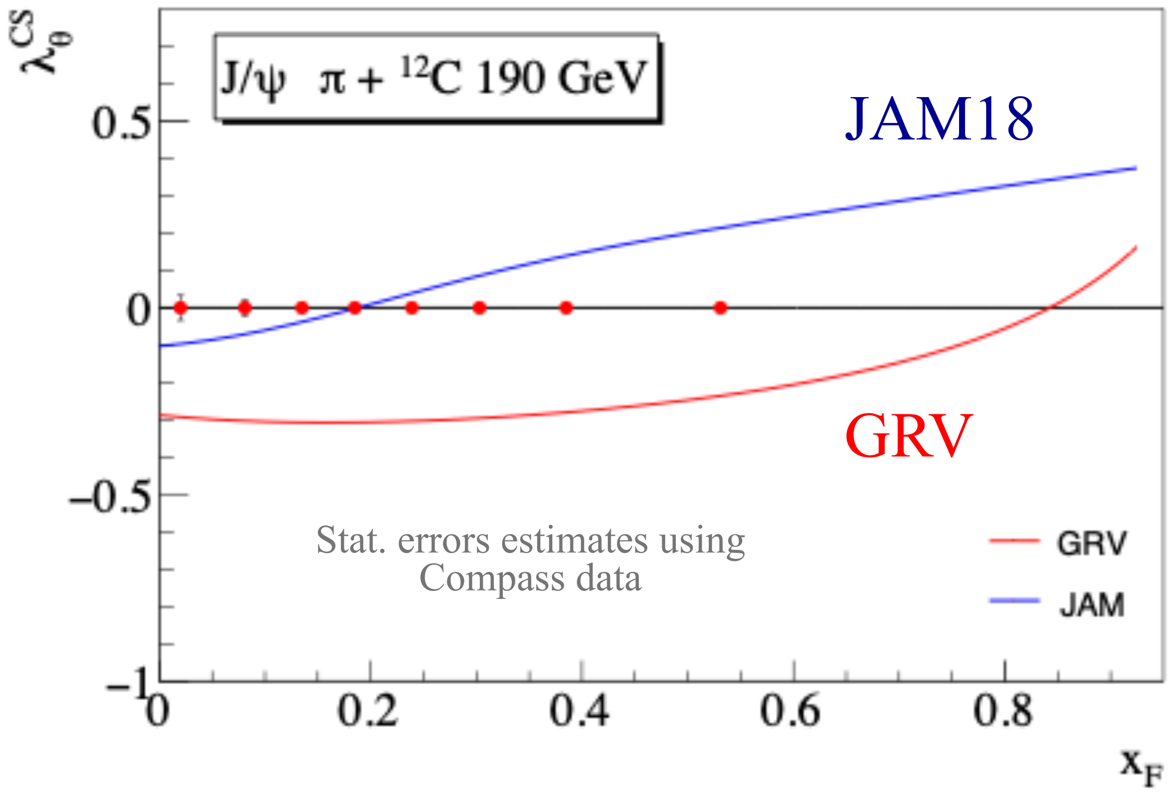
Polarization

- J/ψ is a 1^{--} particle; its third component is $J_z = 0, +1, -1$.
  - $\alpha = +1$: 100% transverse polarization ($J_z = \pm 1$)
  - $\alpha = 0$: unpolarized
  - $\alpha = -1$: 100% longitudinal polarization ($J_z = 0$)

$$\frac{d\sigma}{d(\cos\theta)} \propto 1 + \alpha\cos^2\theta,$$

- Polarization observable
  - angular momentum, chirality, parity conservations preserve the properties of the J/ψ: from production to the 2μ decay
  - Nature wants to help us, for $q\bar{q}$: $\alpha \simeq +1$, but for gg: $\alpha \simeq -1$
  - Key variable for understanding the bound state formation

Polarization: expected results (Cheung and Vogt, priv. comm)



Formulas provided by Faccioli

The polarization value as a function of x_F is sensitive to the shape differences between gg and $q\bar{q}$ contributions to the cross section

Data used

Table 1

J/ψ and Υ polarization measurements in fixed target experiments, characterized by several beam energies (E_{lab}) and angular coverages, denoted using x_F, centre-of-mass rapidity (y_{cms}) or fractional momentum of the beam partons (x_1).

Exp. [Ref.]	Beam	Target	E_{lab} (GeV)	$\sqrt{s}$ (GeV)	Δx_F	Δp_T (GeV)	$\langle p_T \rangle$, $\langle p_T^2 \rangle$ (GeV), (GeV^2)
				J/ψ			
E537 [31]	π^-, $\bar{p}$	W	125	15.3	0.0–0.7	0–2.5	$\langle p_T \rangle = 1.04$
WA11 [32]	π^-	Be	146	16.6	0.0–0.4	0–2.4	$\langle p_T \rangle = 1.0$
NA60 [33]	In	In	158	17.2	y_{cms}: 0–1	≈0–4	
E444 [34]	$\pi^\pm$	C, Cu, W	225	20.6	x_1: 0.2–1.0	0–2.5	$\langle p_T \rangle = 1.2$
E615 [35]	$\pi^\pm$	W	252	21.8	0.25–1.0	0–5	
NA3 [36]	π^-	H, Pt	280	22.9	0.0–1.0		$\langle p_T^2 \rangle = 1.52, 1.85$
WA92 [37]	π^-	Si, Cu, W	350	25.6	≈0.0–0.8	0–4	
E672/706 [38]	π^-	Be	515	31.1	0.1–0.8	0–3.5	$\langle p_T \rangle = 1.17$
E672/706 [39]	p	Be	530, 800	31.5, 38.8	0.0–0.6		$\langle p_T \rangle = 1.15, 1.22$
E771 [40]	p	Si	800	38.8	−0.05–0.25	0–3.5	$\langle p_T^2 \rangle = 1.96$
E866 [41]	p	Cu	800	38.8	≈0.0–0.5	≈0–4	
HERA-B [42]	p	C, Ti, W	920	41.6	−0.34–0.14	0–5.4	$\langle p_T^2 \rangle = 2.2$
				$\Upsilon(1S)$ and $\Upsilon(2S)+\Upsilon(3S)$			
E866 [43]	p	Cu	800	38.8	0.0–0.6	0–4	$\langle p_T \rangle = 1.3$

Measurements shown: Upsilon

- Difference between Y(1S) and Y(2S)+ Y(3S)
  - ”astounding difference”

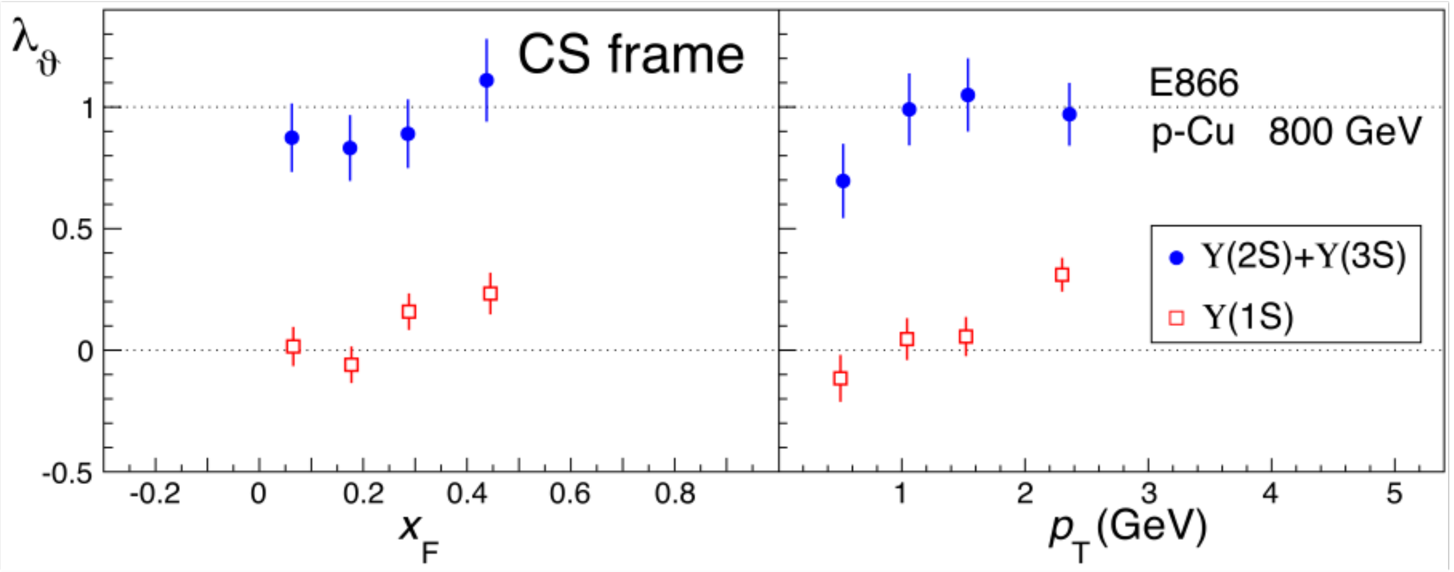


Fig. 2. The Υ(1S) and Υ(2S+3S) polar anisotropy parameter λ_ϑ measured by E866 in the CS frame, vs. x_F and p_T.

HX, GJ, CS frame analysis of HERA-B data

- Observations
  - Inverse hierarchy for Theta and Phi results
  - Reflects the difference between the frame definition
  - A trend towards longitudinal J/psi polarization at small x_F.
  - Interpretation: *gg* process is dominant

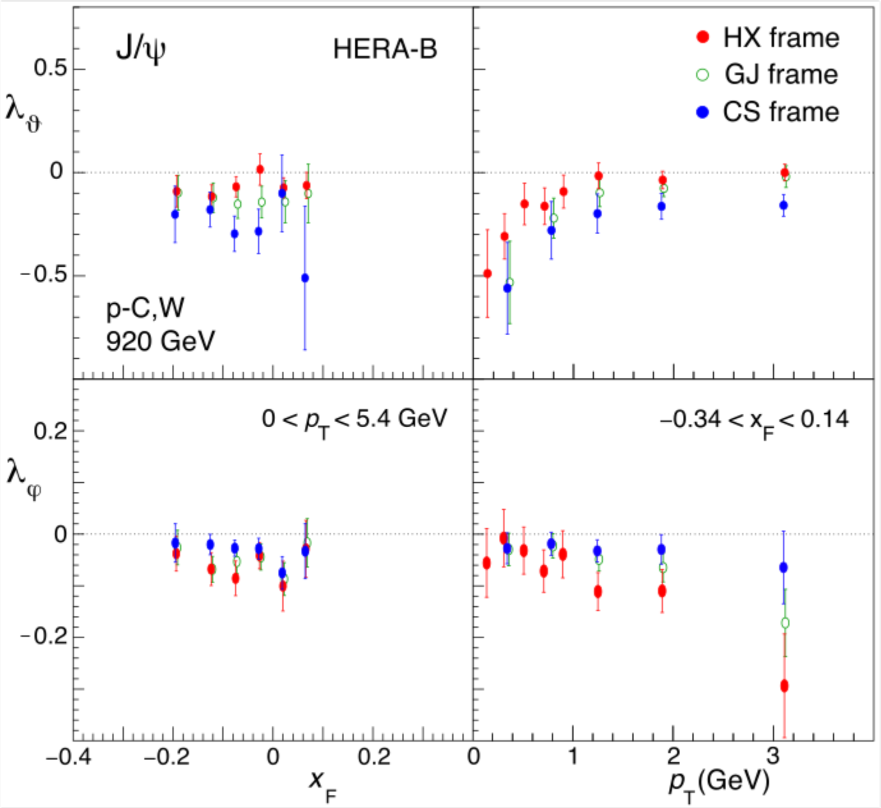


Fig. 3. The J/ψ λ_ϑ and λ_φ parameters measured by HERA-B in the CS, GJ and HX frames, vs. x_F and p_T.

Model used

- Assumptions

  - QQ production is dominated by 2-to-1 topologies, so that contributions producing at least one additional object besides the quarkonium, are considered negligible.

  - The gg → QQ and qq → QQ processes lead, respectively, to fully longitudinal and fully transverse polarizations of the directly produced J/ψ , ψ (2S), and Υ mesons.

Model used

- Relative proportion of qqbar and gg:

$$R = \frac{\sum_q [F_1^q(x_1,\hat{s})\, F_2^{\bar{q}}(x_2,\hat{s}) + F_1^{\bar{q}}(x_1,\hat{s})\, F_2^q(x_2,\hat{s})]}{F_1^g(x_1,\hat{s})\, F_2^g(x_2,\hat{s})},$$

Use the PDFs to calculate it

- Ratio of qqbar and gg cross sections:

$$r = \frac{\hat{\sigma}(q\bar{q} \to \mathcal{Q})}{\hat{\sigma}(gg \to \mathcal{Q})},$$

Fit r to the data: (only parameter)

- Compute the polarization using: $f_{q\bar{q}} = R \times r/(1 + R \times r)$ and $f_{gg} = 1/(1 + R \times r)$,

$$\lambda = \frac{f_{q\bar{q}}\, \lambda^{q\bar{q}}/(3 + \lambda_\vartheta^{q\bar{q}}) + f_{gg}\, \lambda^{gg}/(3 + \lambda_\vartheta^{gg})}{f_{q\bar{q}}\, /(3 + \lambda_\vartheta^{q\bar{q}}) + f_{gg}\, /(3 + \lambda_\vartheta^{gg})}.$$

Assumed polarizations λgg and λqq (from -1 and +1) to values corrected for feed-down (upp, low, central)

Ratio of qqbar to gg "luminosities" for a proton beam

- Luminosity = product of PDFs

- Observations
  - Dominance of *gg* near $x_F = 0$
  - Large difference J/ψ vs Y

- General
  - Low p_T data: 2 ---> 1 process
  - qq = transverse pol.; gg = longitudinal pol.

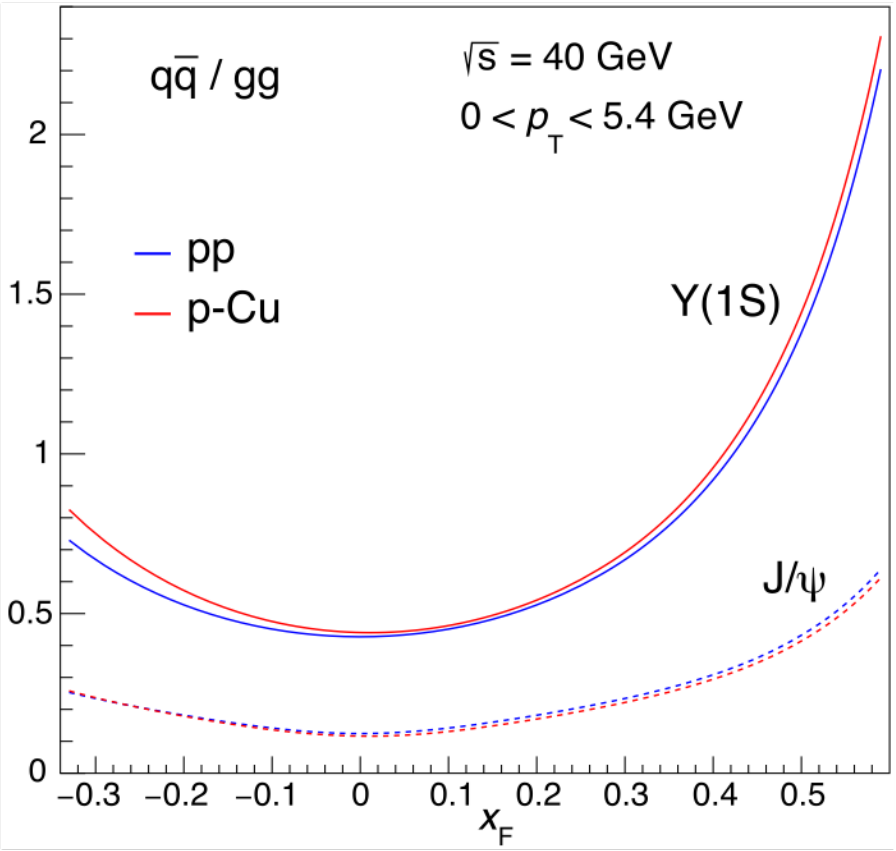


Fig. 4. The $q\bar{q}$ to gg parton luminosity ratios for J/ψ and Υ(1S) production, vs. x_F, illustrated for conditions similar to those of the E866 and HERA-B experiments.

Model vs Data for proton-nucleus collisions

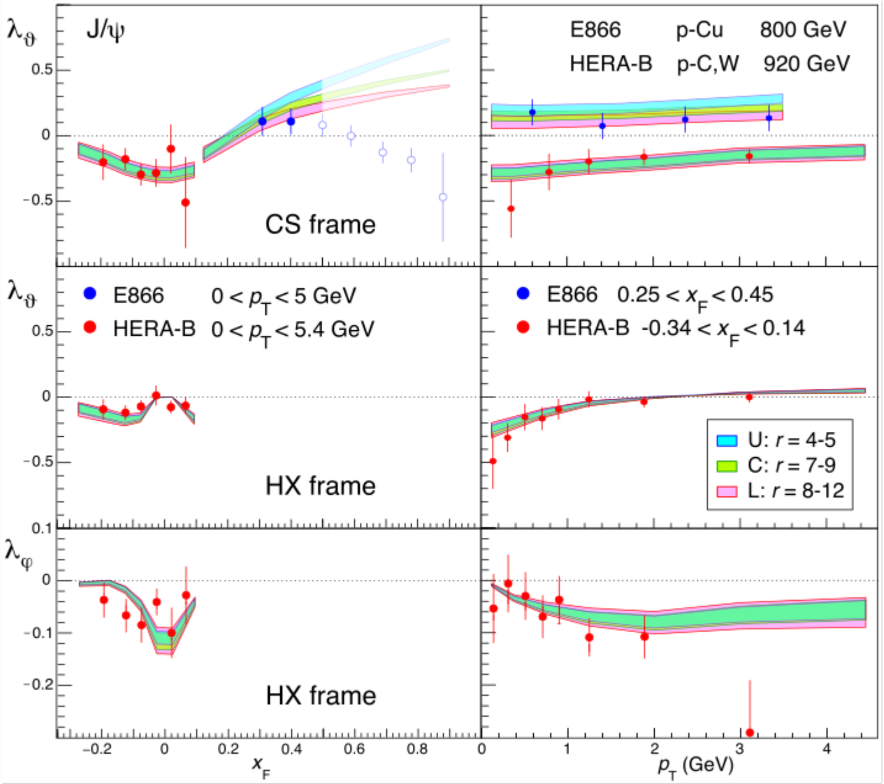


Fig. 6. The x_F (left) and p_T (right) dependences of the J/ψ polarization parameters λ_ϑ in the CS (top) and HX (middle) frames, and λ_φ in the HX frame (bottom), as measured by HERA-B (red points) and E866 (blue points). The cyan, green, and magenta bands represent, respectively, the upper (U), central (C), and lower (L) scenarios described in the text; they are independently computed for the HERA-B and E866 conditions. The departure of the bands from the E866 measurements for $x_F > 0.45$ (open circles) justifies the conjecture that our model is not valid to describe high-x_F quarkonium production.

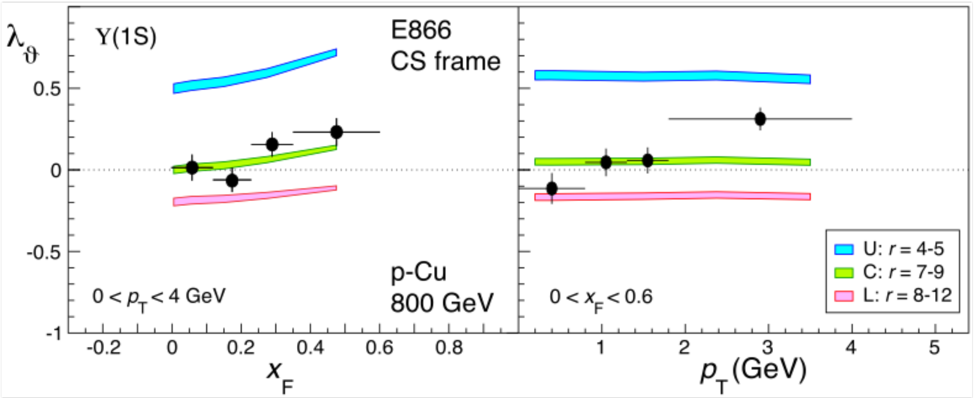


Fig. 7. Same as Fig. 6, for the $\Upsilon(1S)$ λ_ϑ parameter measured by E866 in the CS frame.

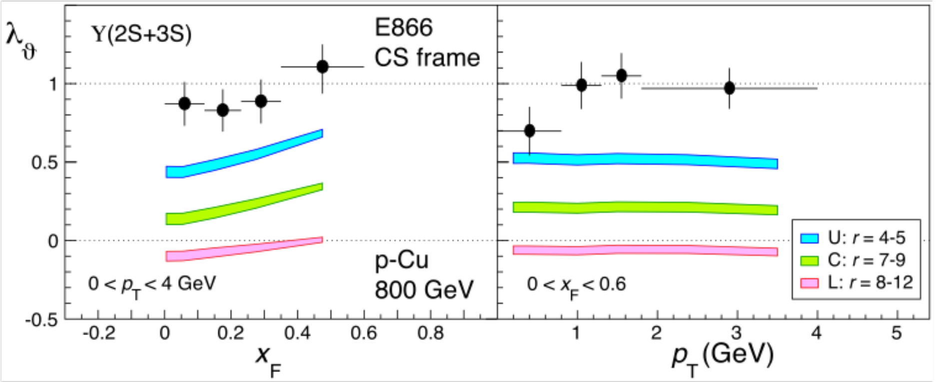


Fig. 8. Same as Fig. 7, for the $\Upsilon(2S+3S)$.

“As mentioned before, these Υ(2S+3S) measurements are clearly a notable exception in the global panorama of the existing data. Faced with this large discrepancy, we must wonder if there could be some experimental factor causing a difference between the Υ(2S+3S) measurement and the J/ψ or Υ(1S) measurements.”

Pion-nucleus collisions

- Observations
  - Very large effect, as expected.

“The x_F dependence of this ratio, as well as its average value and the covered x_F range, depend quite significantly on the chosen PDF set, probably because of the poorly-known gluon density in the pion”

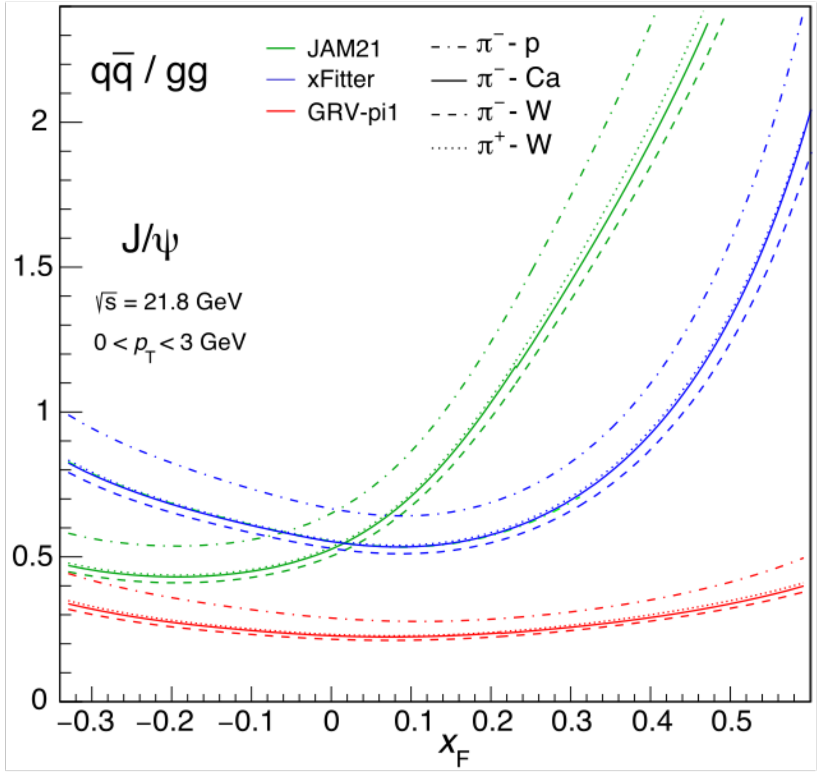


Fig. 9. The $q\bar{q}$ over gg parton luminosity ratios, vs. x_F, for J/ψ production at the collision energy of E615 [35], for the JAM21, xFitter, and GRV-pi1 pion PDF sets, and for the π^-p, π^--Ca, π^--W, and π^+-W collision systems.

Pion-nucleus collisions

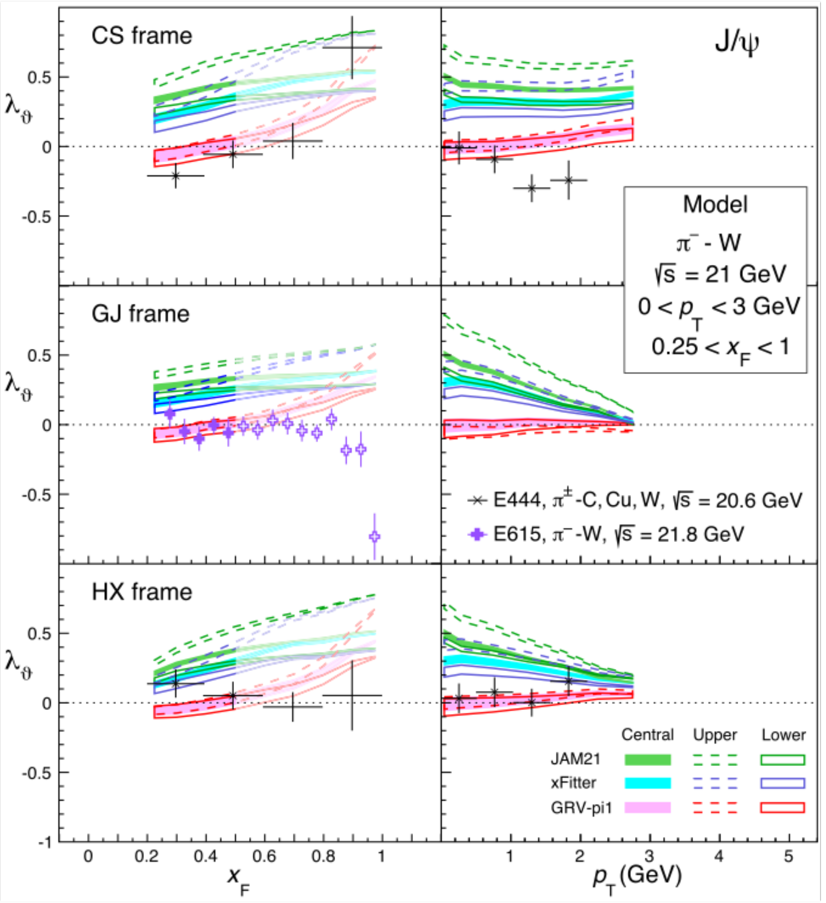


Fig. 10. The x_F and p_T dependences of the J/ψ λ_ϑ parameter, in the CS, GJ, and HX frames, as measured by E444 and E615 in π-W collisions. The bands are computed using the JAM21, xFitter, and GRV-pi1 pion PDF sets, for the three feed-down scenarios. As in Fig. 6, the data points and bands are displayed less prominently in the $x_F > 0.5$ region.

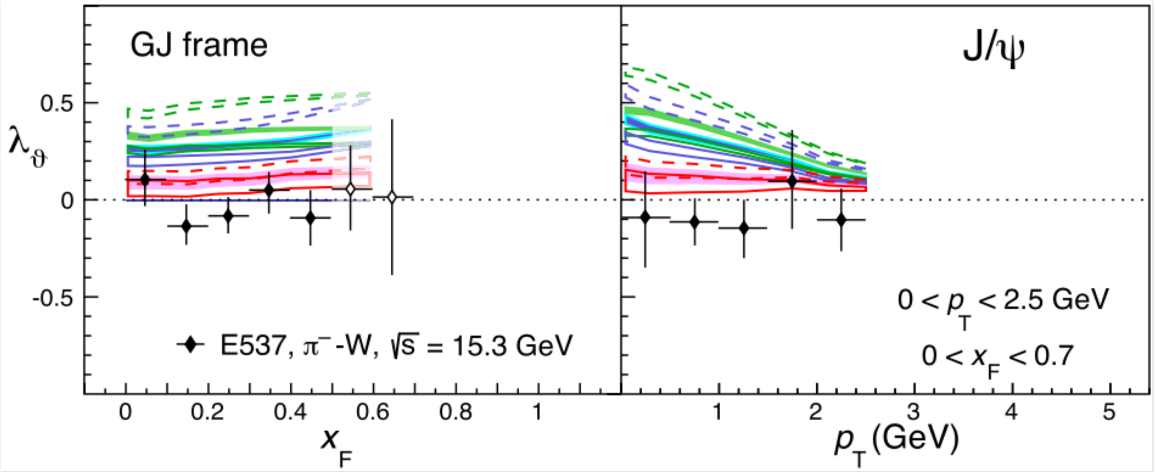


Fig. 11. Same as Fig. 10, for the E537 conditions.

Confirmation: GRV produces the best agreement

Predictions for AMBER

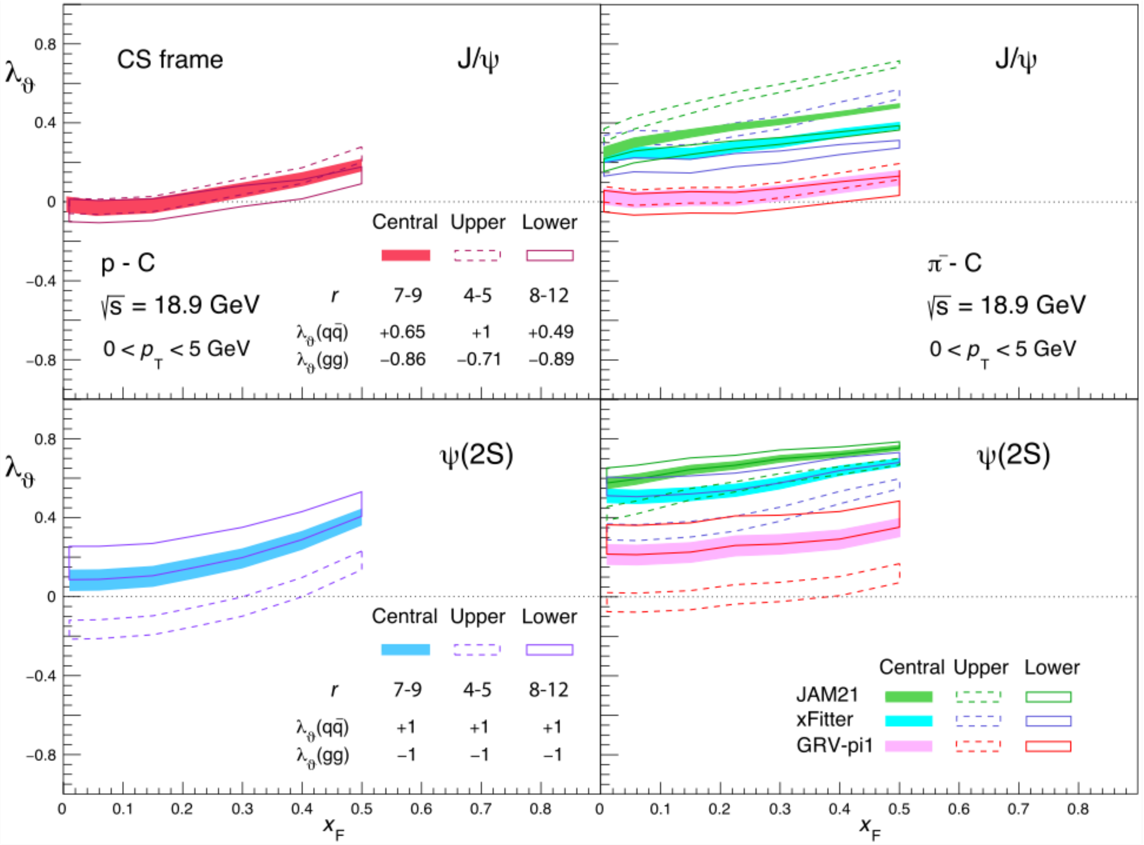


Fig. 12. The x_F dependence of the λ_ϑ parameter, in the CS frame, as predicted for J/ψ (top) and ψ(2S) (bottom) production in p-C (left) and π^--C (right) collisions at $\sqrt{s} = 18.9$ GeV (corresponding to the conditions of the AMBER experiment), for the three considered J/ψ feed-down scenarios. The bands on the right panels correspond to the three pion PDF sets.