XVII International Workshop on
Deep-Inelastic Scattering and Related Subjects
DIS 2009, 26-30 April 2009, Madrid

Recent results on charmonium production at HERA-B

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for the HERA-B collaboration

Outline and physics motivation

Charmonium production at HERA-B

- ***J/ψ inclusive production***
  - kinematical distributions
  - polarization
  - Nuclear suppression
- ***heavier charmonium states***
  - **J/ψ** feed-down from ψ′ and **χ_c**
  - kinematical distribution of ψ′ and **χ_c**

Test of QCD predictions

results in the negative x_F range

few results for J/ψ-ψ′ polarization

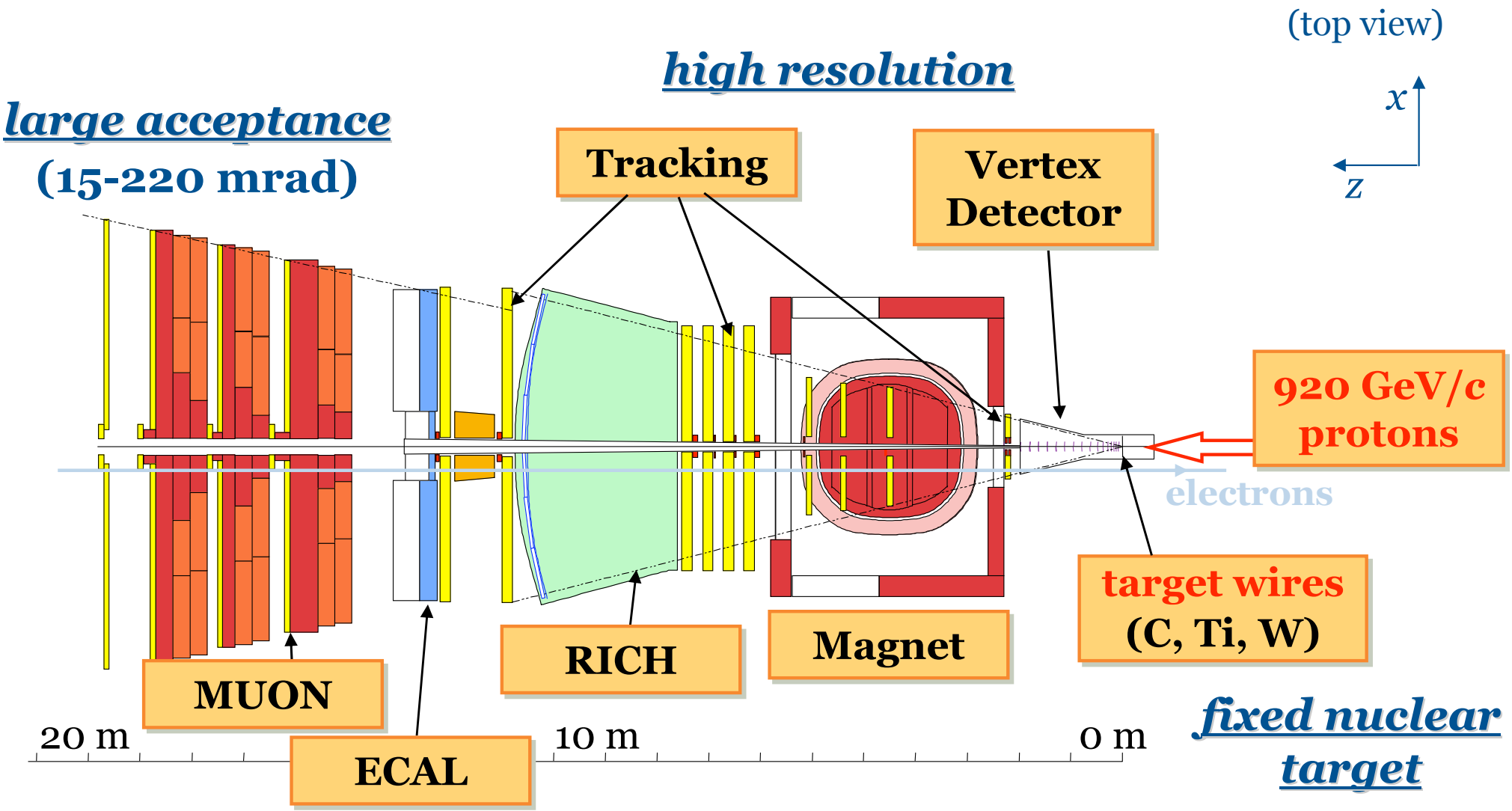
Investigation of nuclear effects

$R(\chi_c/J/\psi)$ few results with poor compatibility

Conclusions

All the presented results have been published

The HERA-B detector



fixed nuclear target

$\sqrt{s}$ = 41.6 GeV

$A = 12 \div 184$

good PID

($e^{\pm}$, $\mu^{\pm}$, π, K, p,γ)

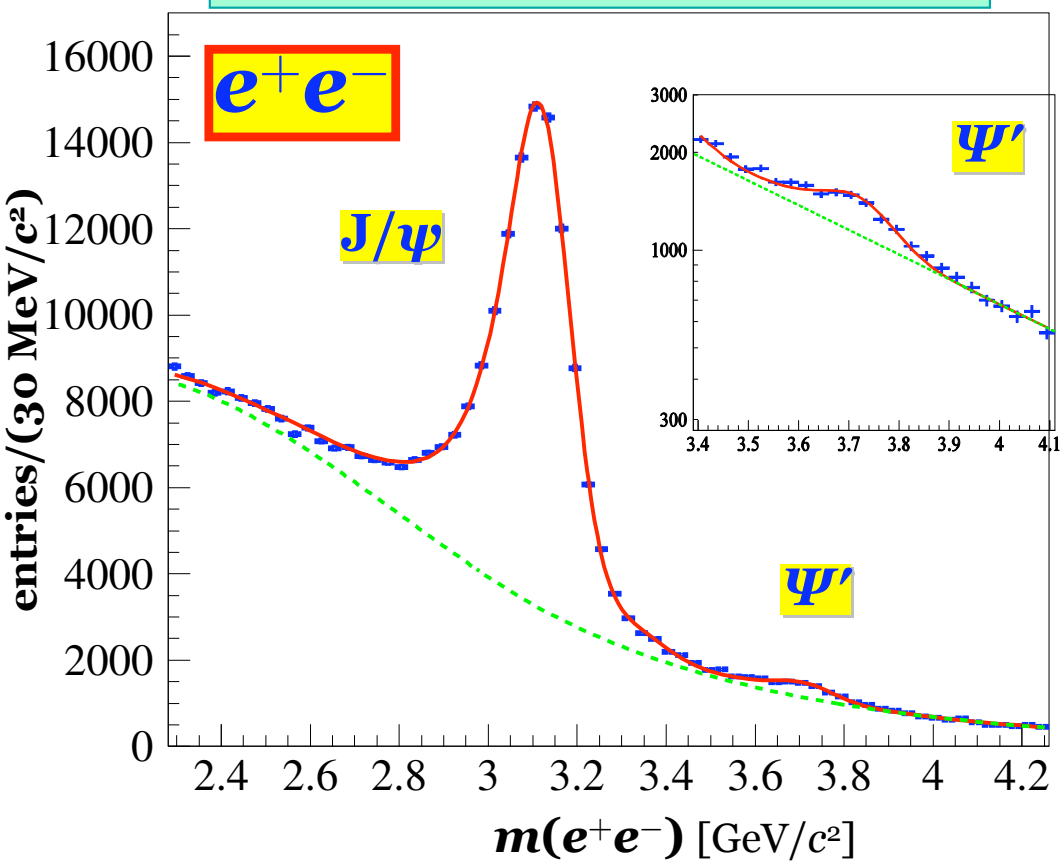
Di-lepton trigger

(ee,$\infty\infty$)

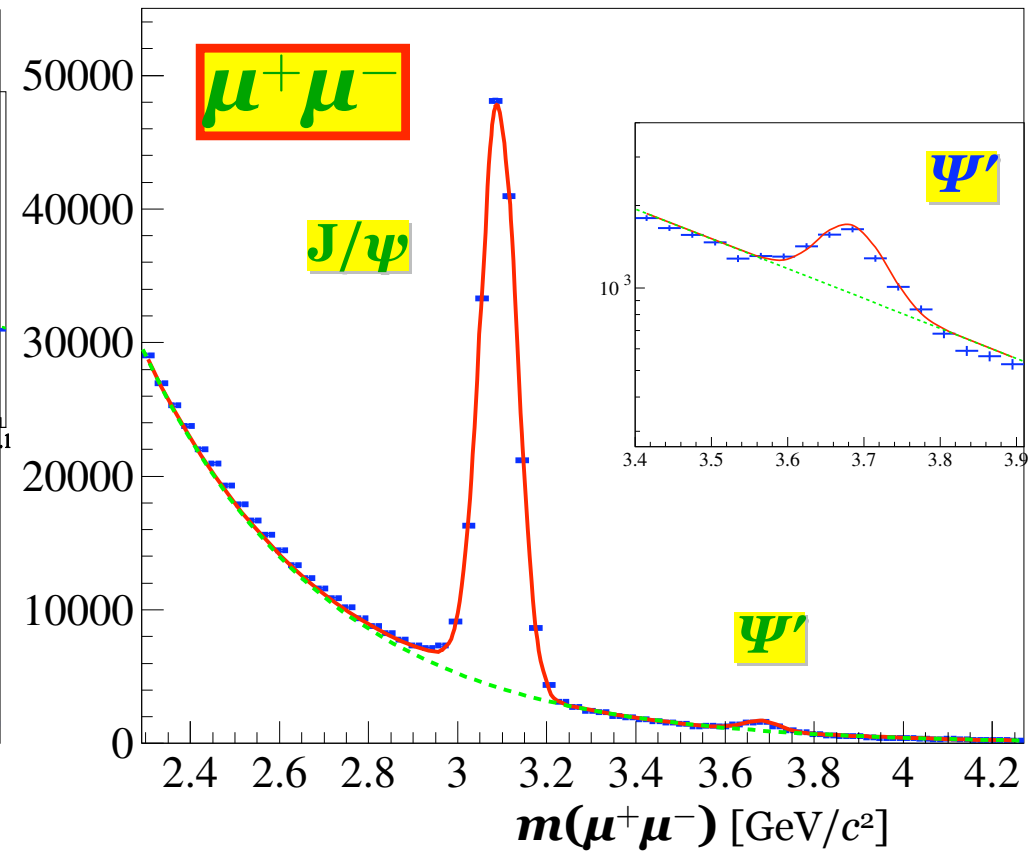
J/ψ and ψ' signals

charmonium analyses performed in both dilepton channels

87200 J/ψ and ~ 1700 ψ'



152000 J/ψ and ~ 2700 ψ'



J/ψ sample: direct J/ψ's + J/ψ's from ψ' and χ_c decays

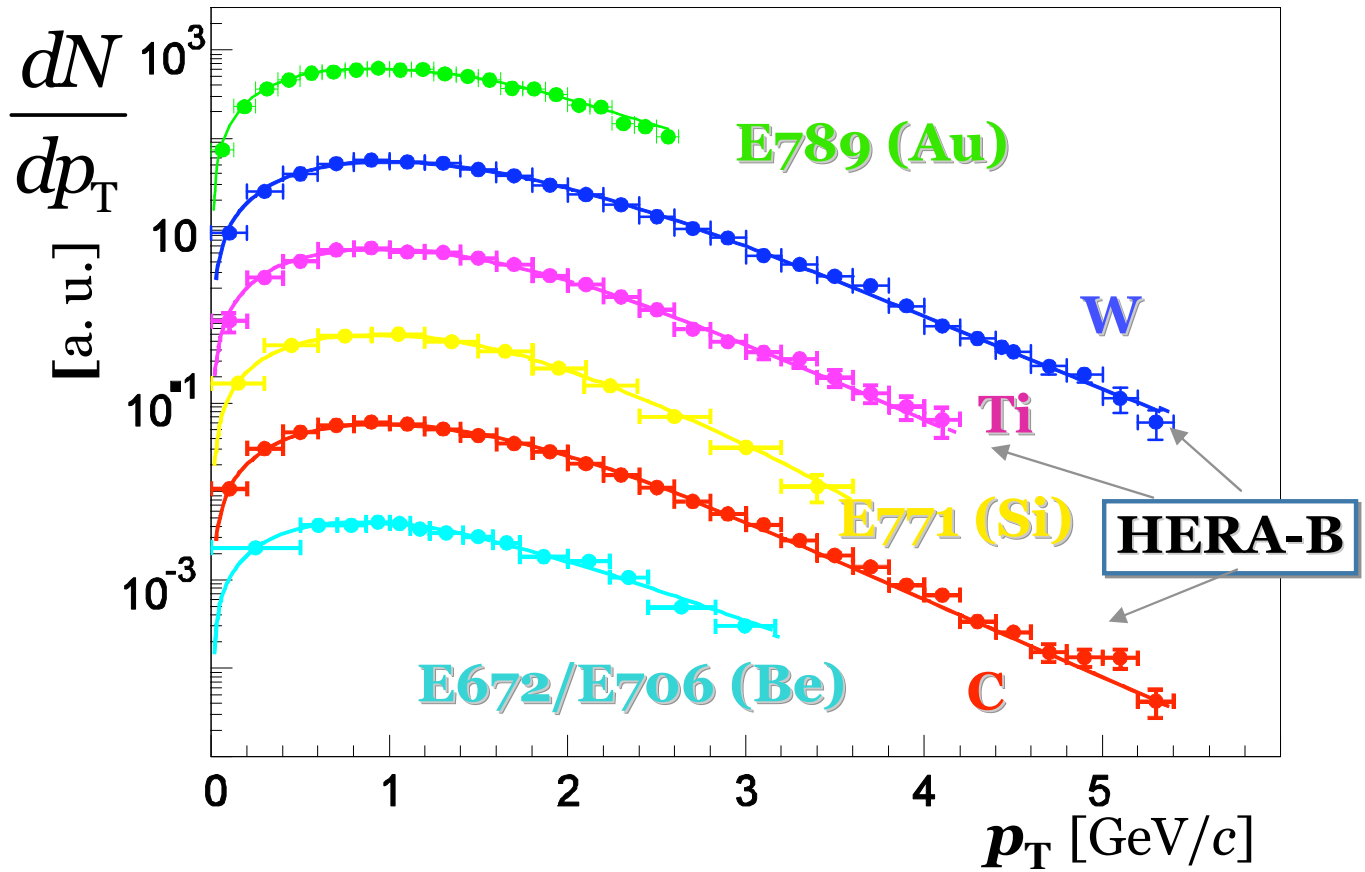
electron channel used strong PID cuts (at least 1BR cluster)

J/ψ → Eur. Phys. J. C60,525,2009

Ψ' → Eur.Phys.J.C49:545-558,2007

J/ψ production kinematic: p_T distribution

Comparison with p-A results at 38.8 GeV

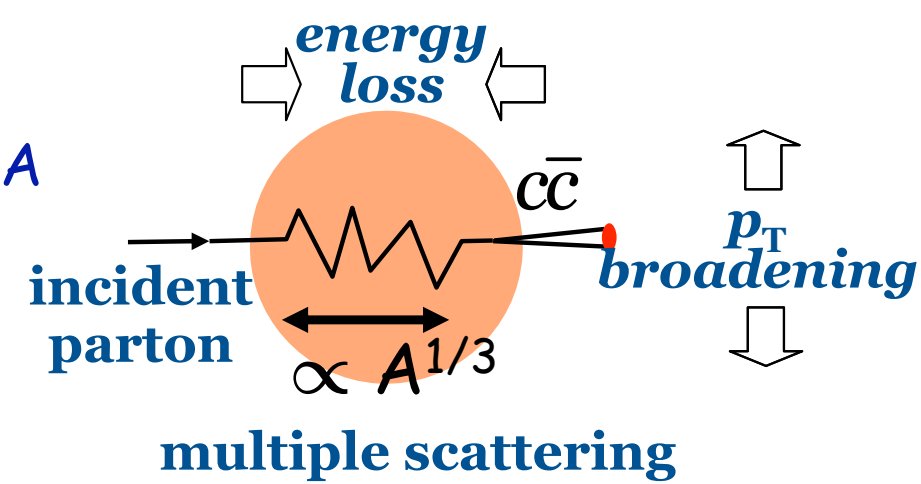


	$\langle p_T^2 \rangle$ (GeV²/c²)
C	2.141 ± 0.017
Ti	2.204 ± 0.040
W	2.432 ± 0.031

$$\frac{dN}{dp_T} \propto p_T \left(1 + \left(\frac{1}{\beta - 2}\right)^2 \frac{p_T^2}{\langle p_T^2 \rangle}\right)^{-\beta}$$

$\langle p_T^2 \rangle$ depend on A

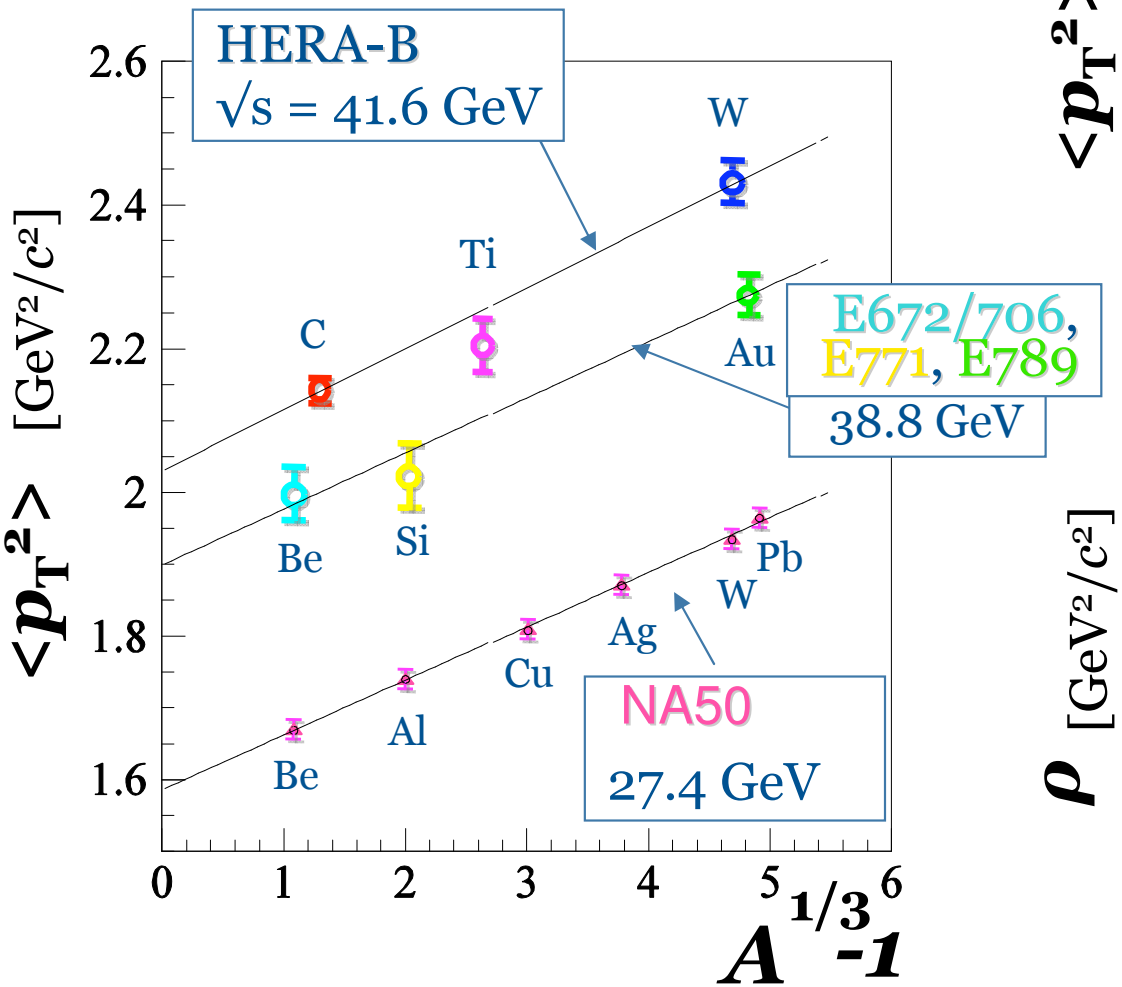
β ~ cost

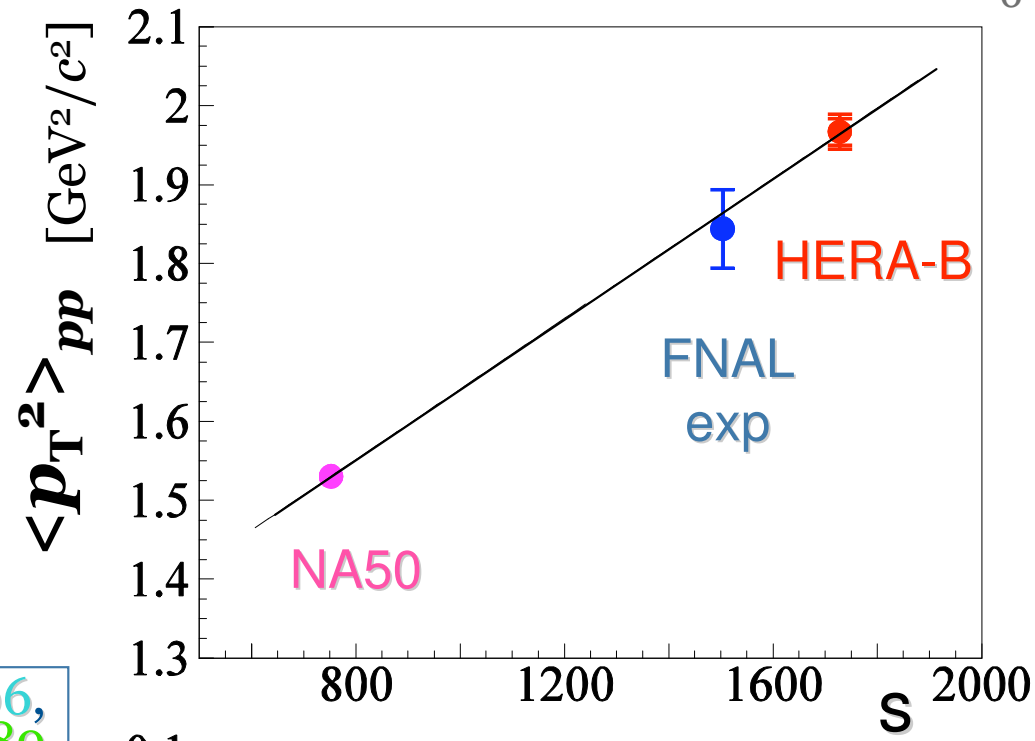


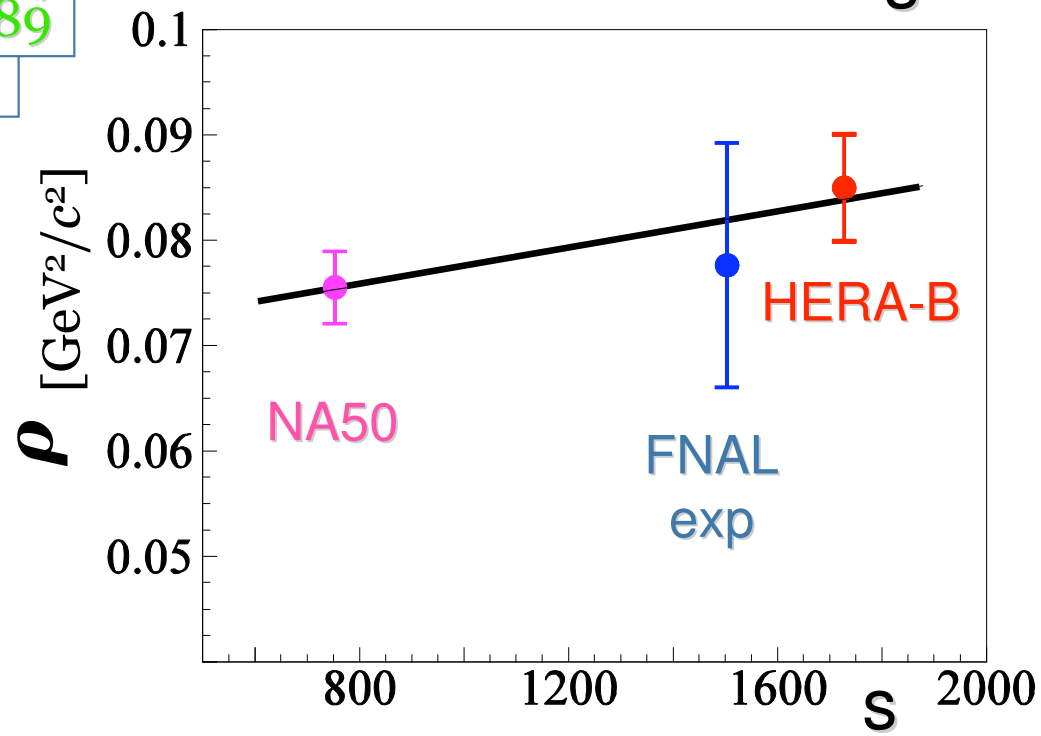
Nuclear effects

$$\langle p_T^2 \rangle_{pA} = \langle p_T^2 \rangle_{pp} + \rho \times (A^{1/3}-1)$$

$\propto L$ (path length)

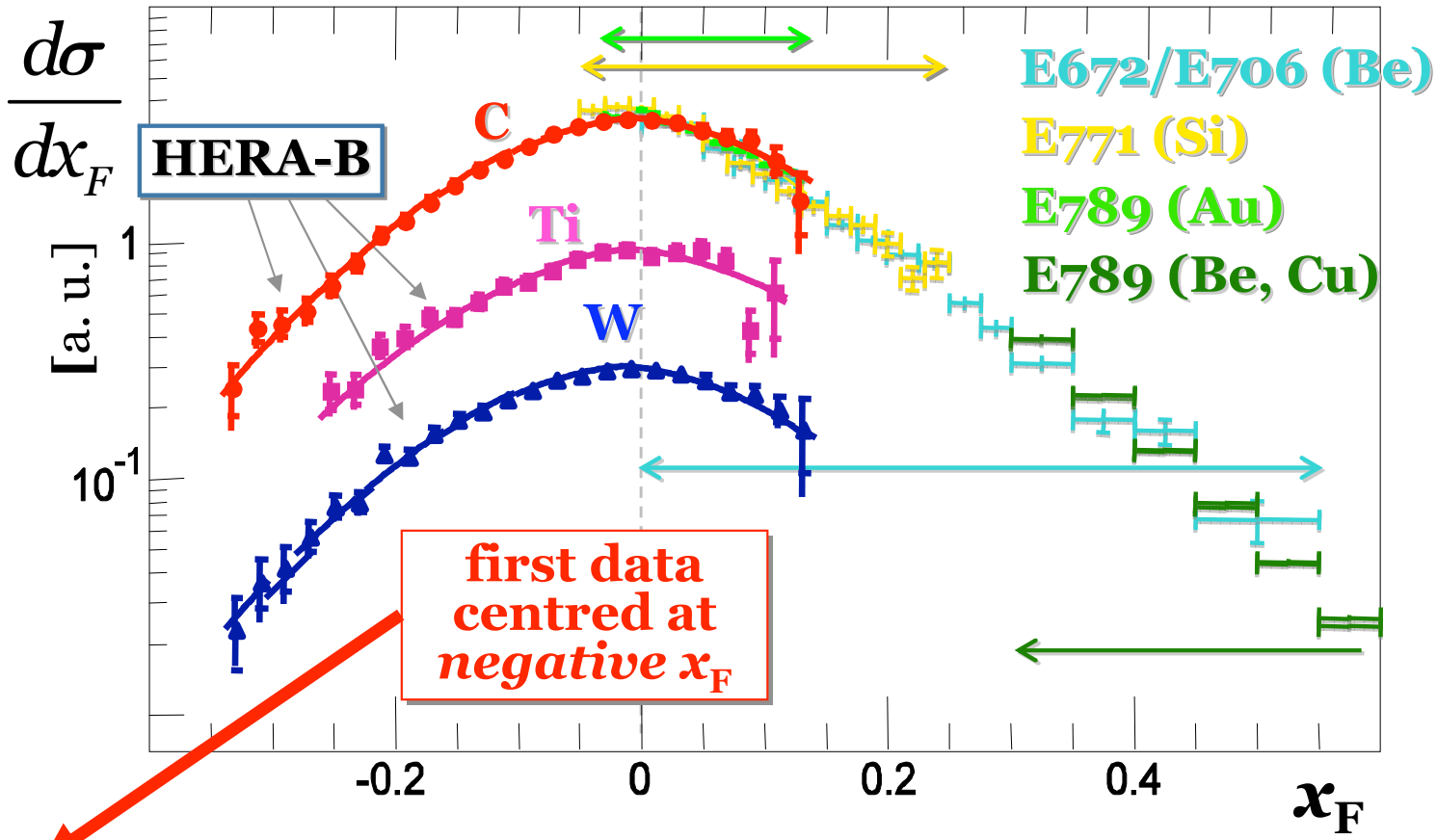






J/ψ production kinematic: x_F distribution

comparison with *p-A* results at 38.8 GeV



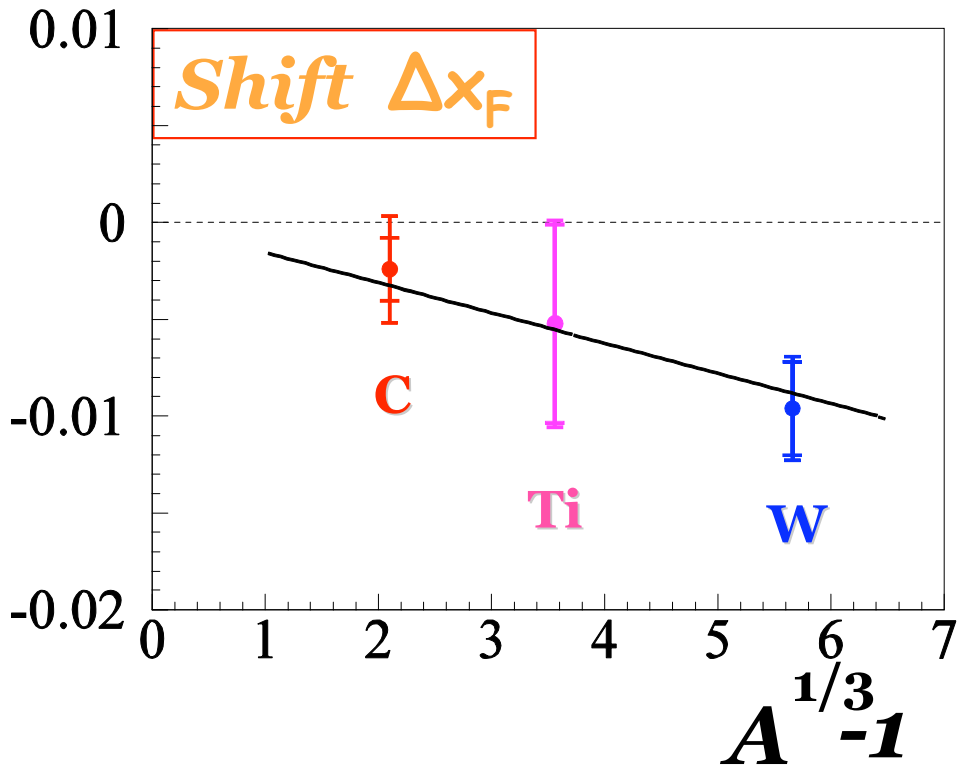
Different range

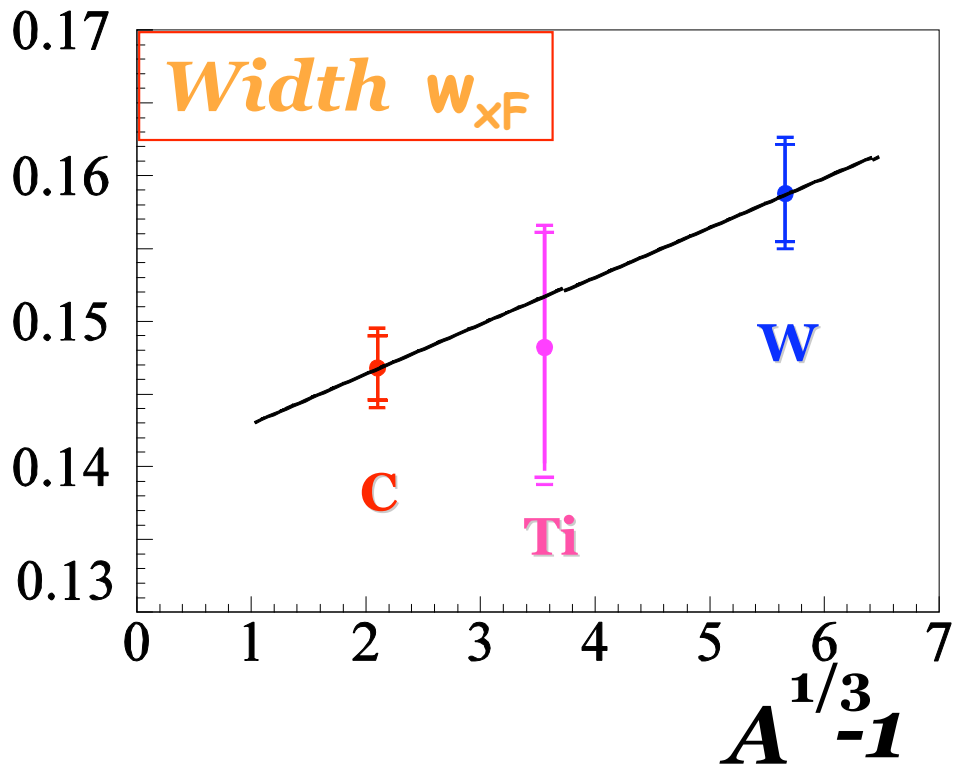
$$\frac{dN}{dx_F} \propto \exp\left(-\ln 2 \left|\frac{x_F - \Delta x_F}{w_{x_F}}\right|^{\gamma}\right)$$

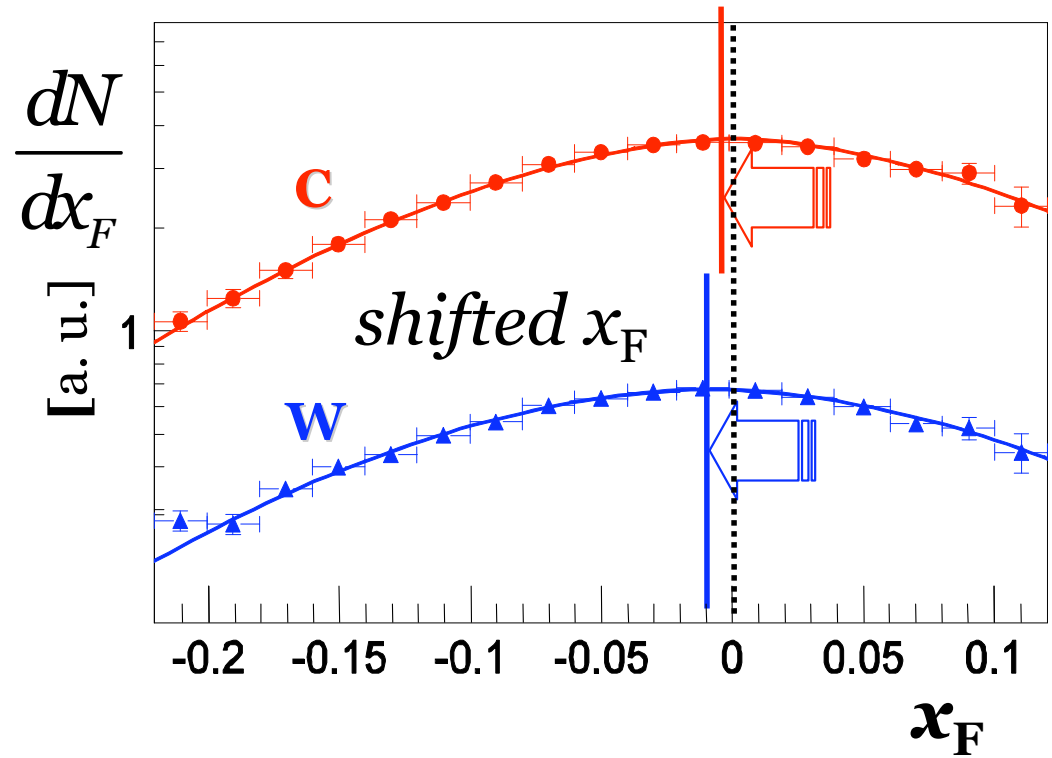
$\gamma \sim$ cost

	w_{xF}	Δx_F
C	0.1468 ± 0.0027	-0.0024 ± 0.0027
Ti	0.1482 ± 0.0084	-0.0052 ± 0.0053
W	0.1588 ± 0.0038	-0.0096 ± 0.0027

Nuclear effects





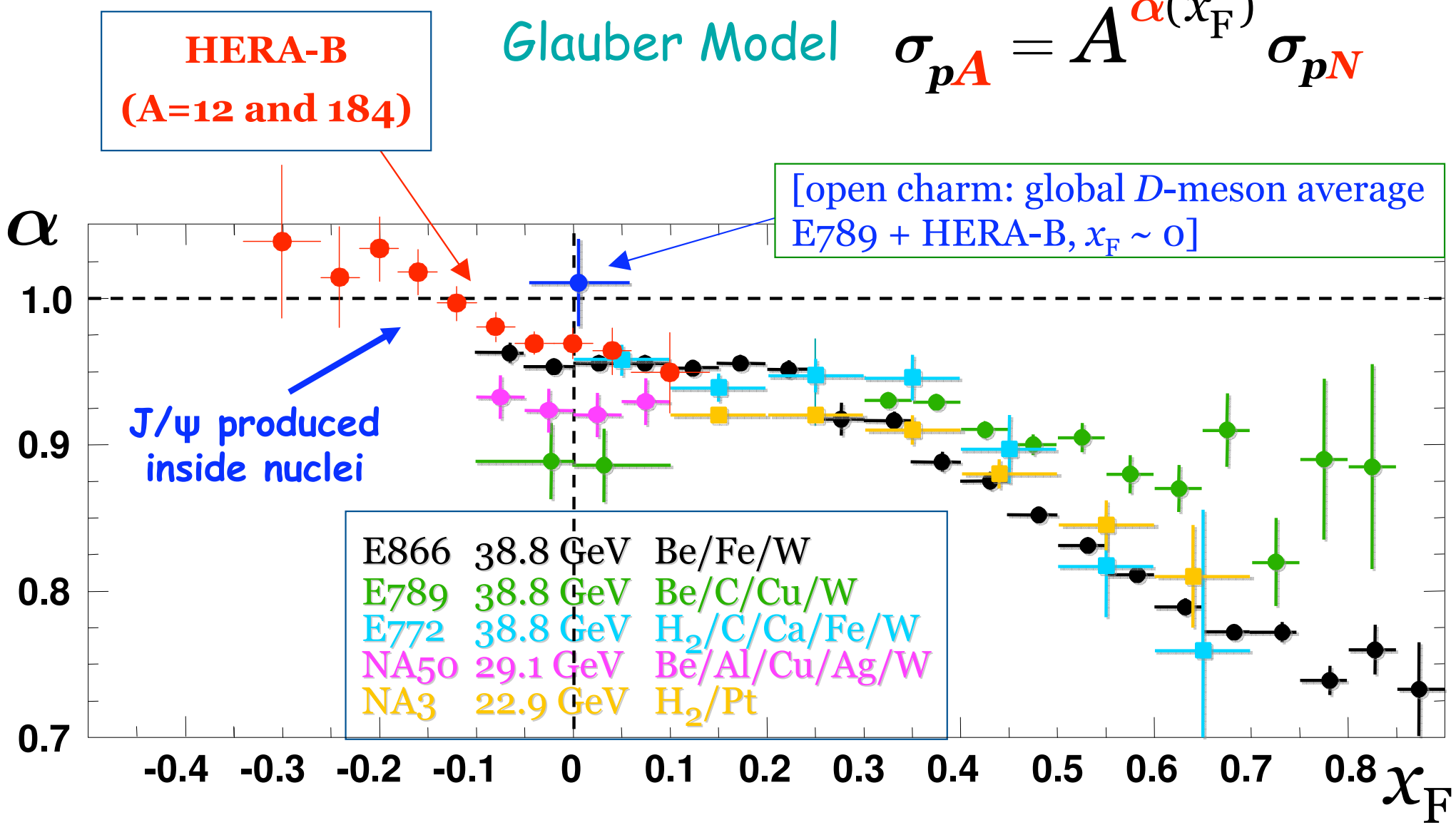


- p_T distribution:
  - increase of $\langle p_T^2 \rangle$ with radius
- x_F distribution:
  - increase width and shift with radius

both effects compatible with initial state energy loss

J/ψ production: nuclear suppression vs x_F

Glauber Model $\sigma_{pA} = A^{\alpha(x_F)} \sigma_{pN}$

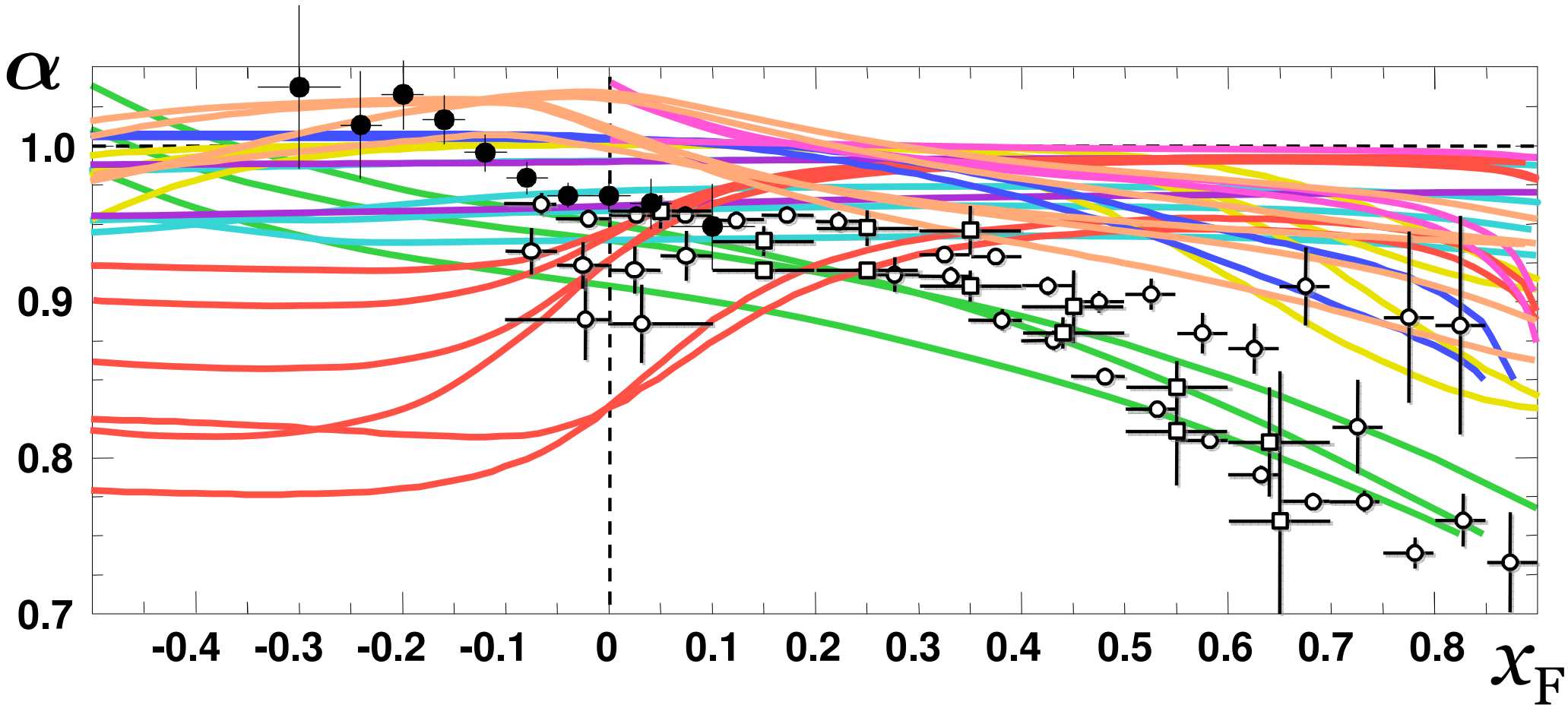


magnitude: better agreement with E866 than with NA50 (energy dependence?)

HERA-B average suppression: $\langle \alpha \rangle = 0.981 \pm 0.004 \pm 0.016$

theory

- modification of the PDFs of nucleons bound in the nucleus
- energy loss of the incident partons (Gavin-Milana/Brodsky-Hoyer/Kharzeev-Satz)
- interaction with comovers produced together with $c\bar{c}$
- intrinsic charm components of beam protons
- interaction with soft partons fluctuating from beam protons
- absorption of cc inside the nucleus



Two leptons decay angular distribution

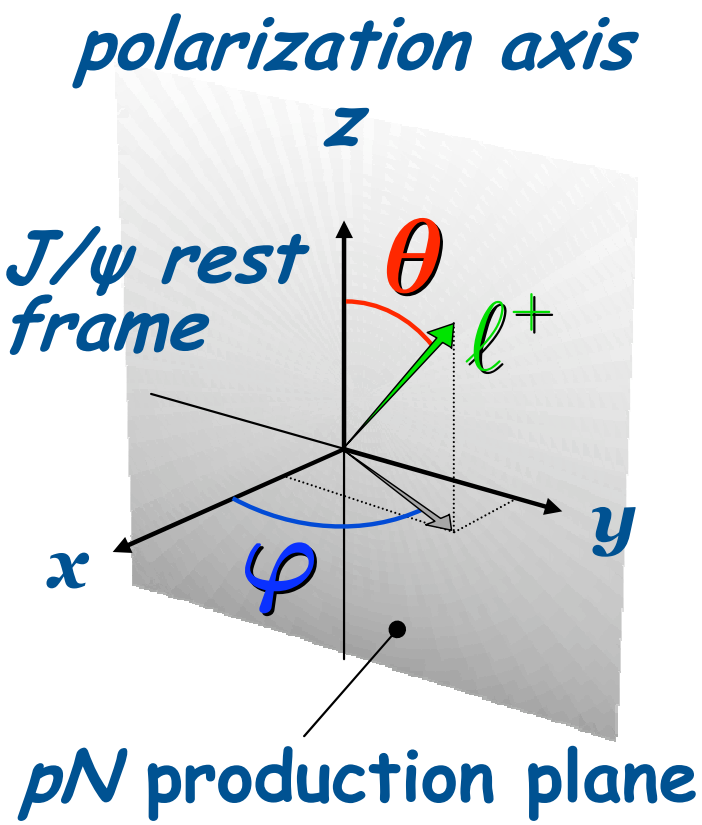
$$\frac{dN}{d(\cos\theta)d\varphi} \propto 1 + \lambda_\theta \cos^2\theta + \lambda_{\theta\varphi} \sin 2\theta \sin\varphi + \lambda_\varphi \sin^2\theta \cos 2\varphi$$

2 dof: $\cos\theta$, φ

Λ_θ is called "polarization"

Λ_θ < 0: longitudinally polarized
= 0: unpolarized
> 0: transversely polarized

any deviation from zero of one parameter is an indication of polarization



1) Collins-Soper (CS): bisector between beam and (-)target in the J/ψ rest frame — **E866, NA3, etc.**

2) Gottfried-Jackson (BEAM): beam direction in the J/ψ rest frame — **E615, E672-706, E771, E537, etc.**

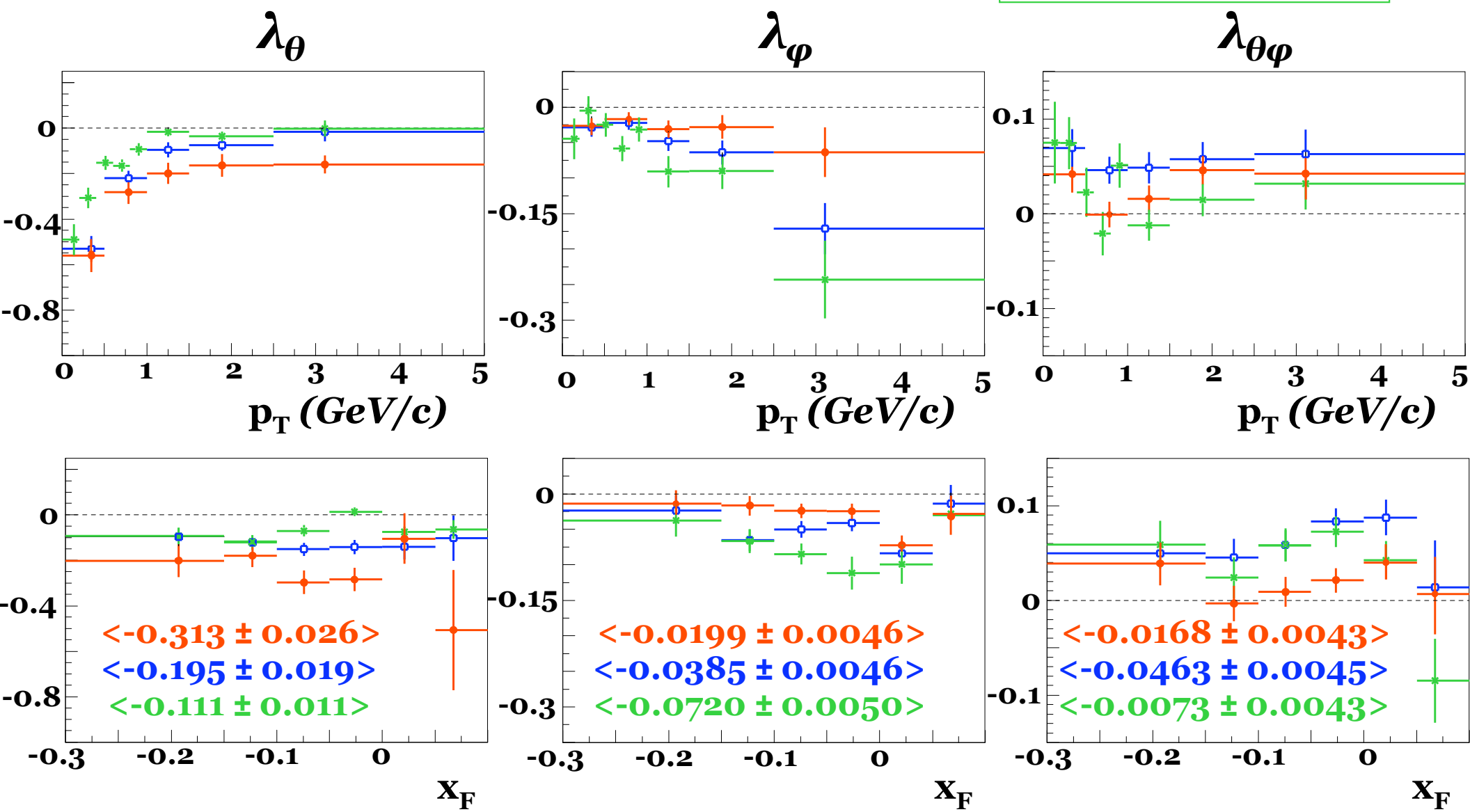
3) helicity (HCM): J/ψ direction in the hadron (p-N) CM frame — **CDF, NA60 ...**

The frames differ by a rotation around x

Eur. Phys. J. C 60, 517 (2009)

J/ψ decay angular distribution

HCM BEAM CS



hierarchy

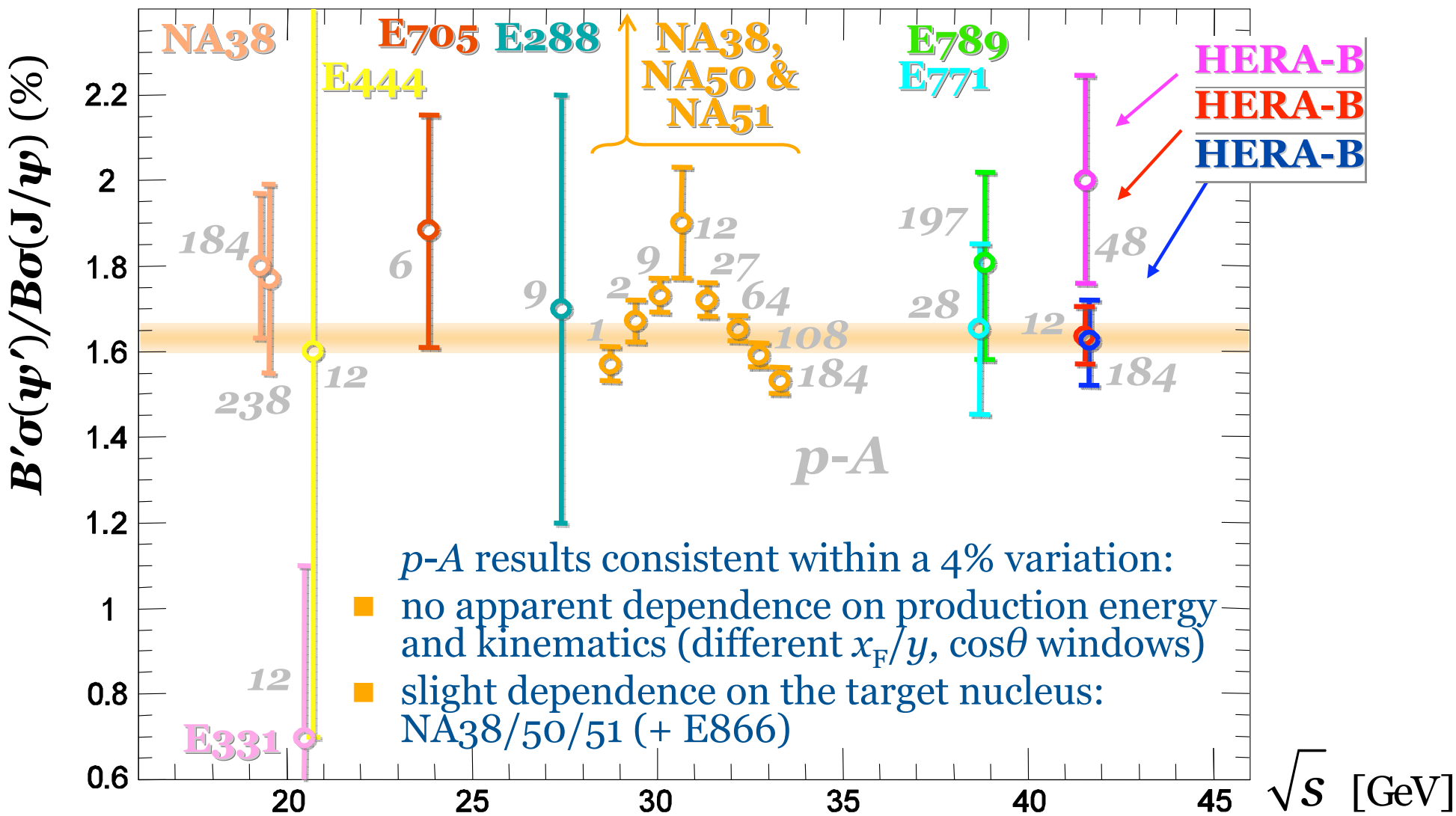
$$|\lambda_\theta(\mathrm{HCM})| < |\lambda_\theta(\mathrm{BEAM})| < |\lambda_\theta(\mathrm{CS})|$$

$$|\lambda_\varphi(\mathrm{HCM})| > |\lambda_\varphi(\mathrm{BEAM})| > |\lambda_\varphi(\mathrm{CS})|$$

ψ'-to-J/ψ production ratio

$$\rho_{\psi'}^{\ell^+\ell^-} = \frac{B_{\psi'\to\ell^+\ell^-}\,\sigma_{\psi'}}{B_{J/\psi\to\ell^+\ell^-}\,\sigma_{J/\psi}} = \begin{cases} 1.63\pm0.08\,\%\,(\mathrm{C}) \\ 1.99\pm0.26\,\%\,(\mathrm{Ti}) \\ 1.62\pm0.11\,\%\,(\mathrm{W}) \end{cases}$$

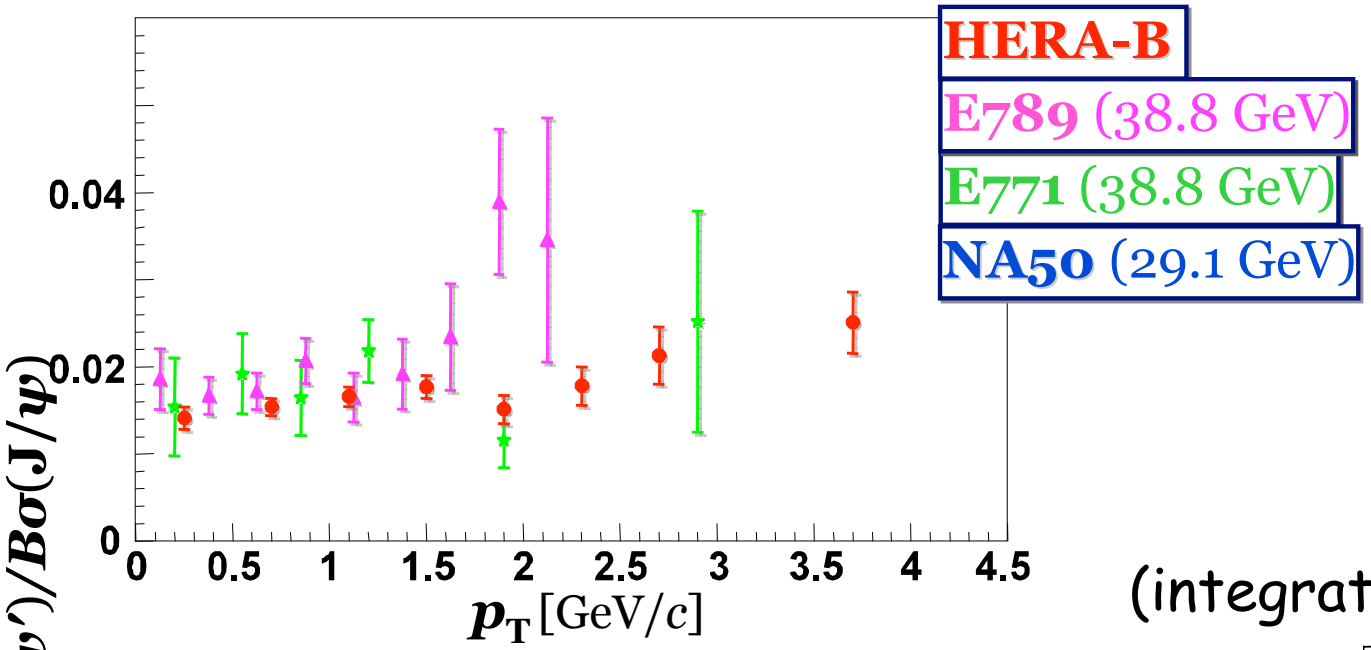
$$R_{\psi'} = \frac{\sigma_{\psi'\to\ell^+\ell^-}}{\sigma_{J/\psi\to\ell^+\ell^-}}\cdot B_{\psi'\to\left\{\begin{smallmatrix} J/\psi\pi^+\pi^- \\ J/\psi\pi^0\pi^0 \\ J/\psi\eta \\ J/\psi\pi^0 \end{smallmatrix}\right.} = (6.8\pm0.4)\%$$



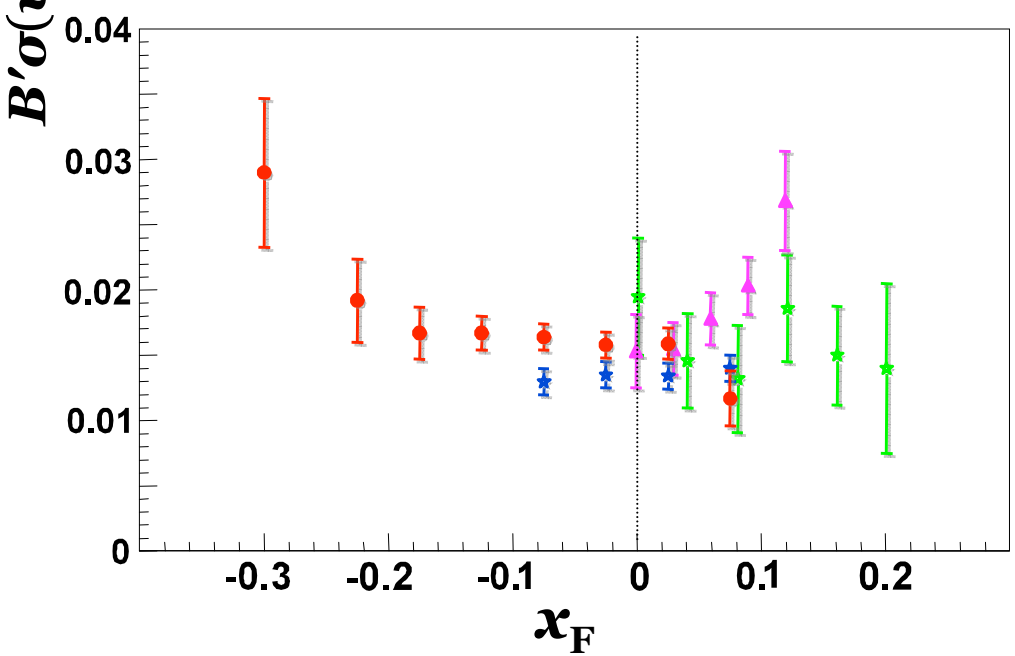
p-A results consistent within a 4% variation:

- no apparent dependence on production energy and kinematics (different x_F/y, $\cos\theta$ windows)
- slight dependence on the target nucleus: NA38/50/51 (+ E866)

ψ' to J/ψ kinematic and angular distributions

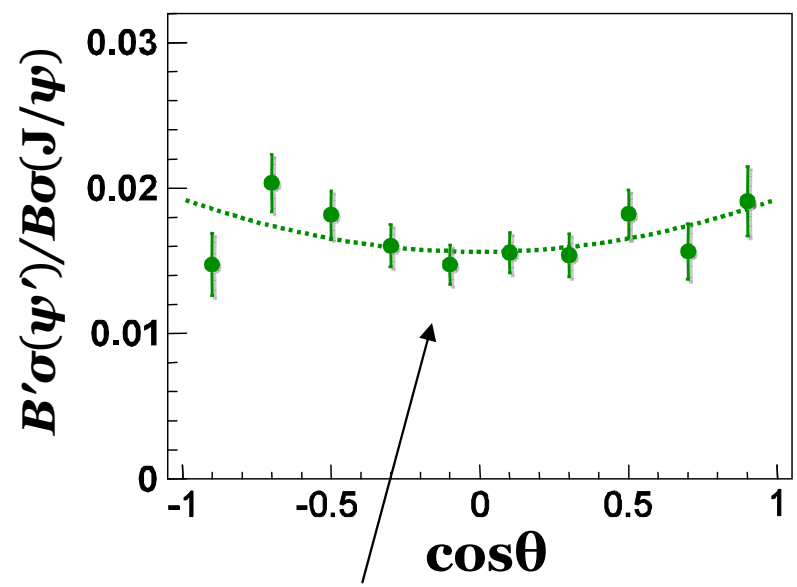


$B'\sigma(\psi')/B\sigma(J/\psi)$ vs x_F. p_T , $\cos\theta$



HCM frame

(integrated over all phase space)



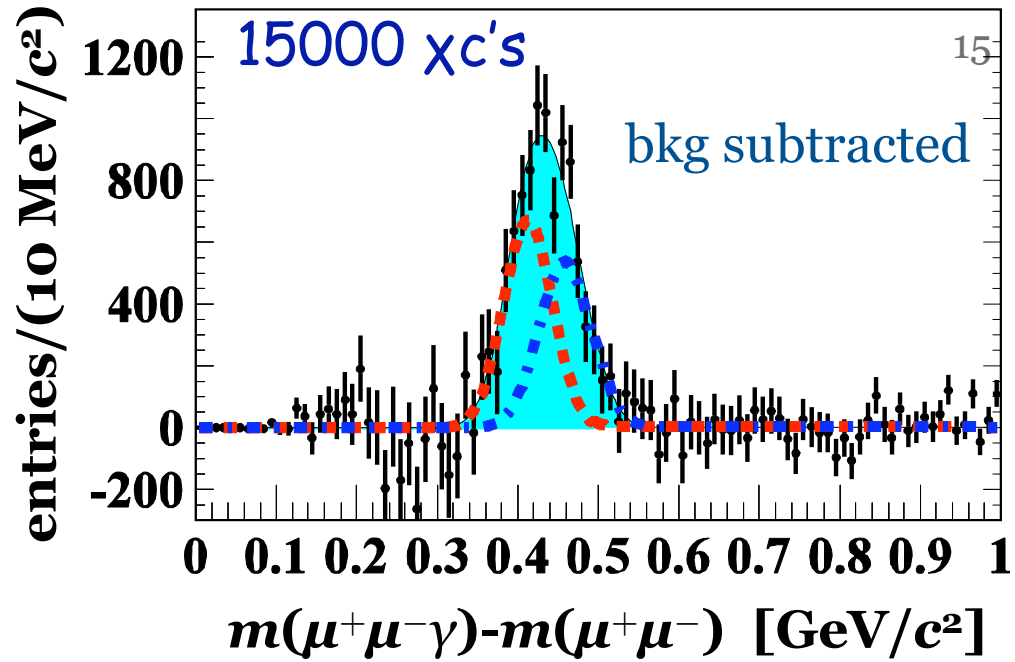
$$\lambda_\theta(\psi') - \lambda_\theta(J/\psi) = 0.23 \pm 0.17$$

X_c production

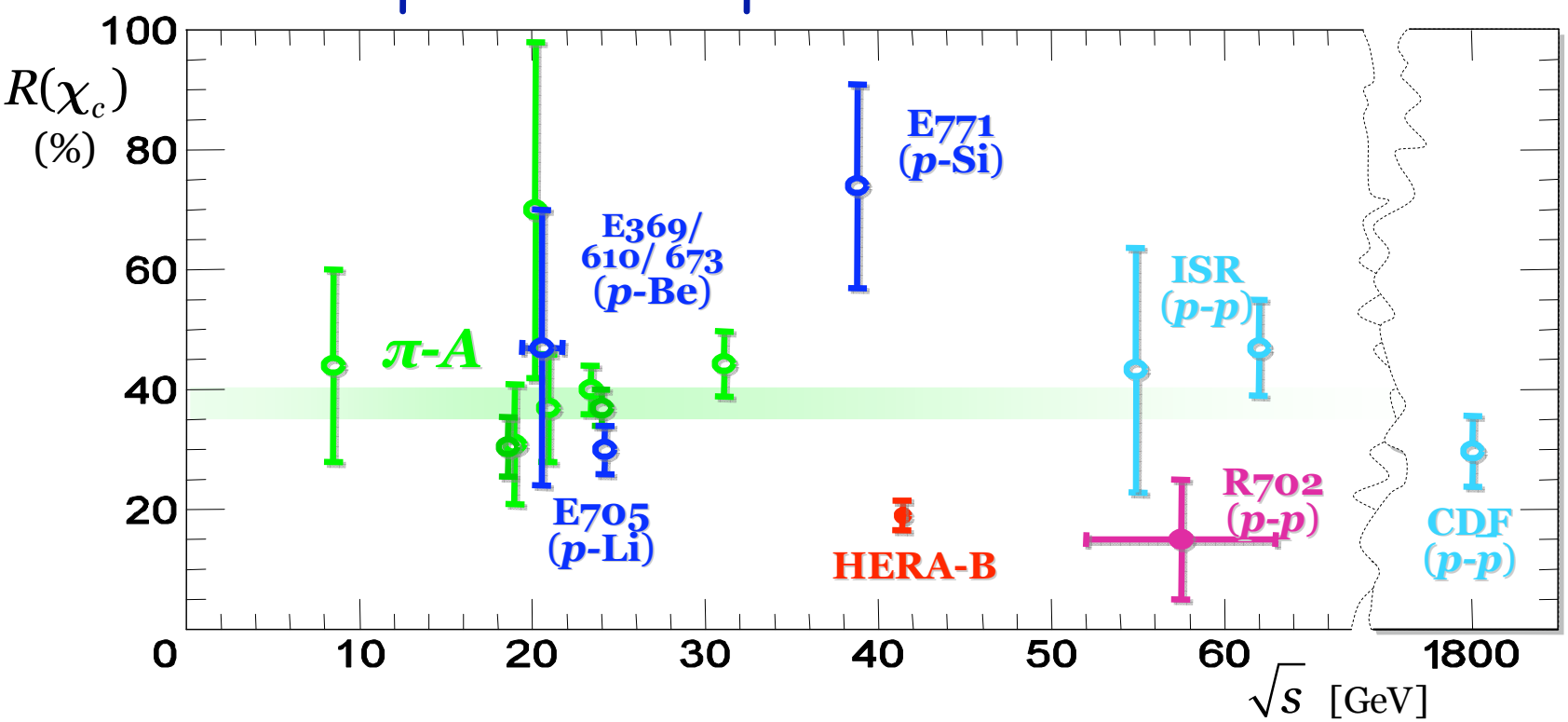
$$\chi_c \to J/\psi\,\gamma \to e^+e^-\left(\mu^+\mu^-\right)\gamma$$

J/ψ Feed-down from χc (Rχc)

$$R(\chi_c) = \left(18.8 \pm 1.3_{stat}\ {}^{+2.4}_{-2.2}{}_{sys}\right)\%$$

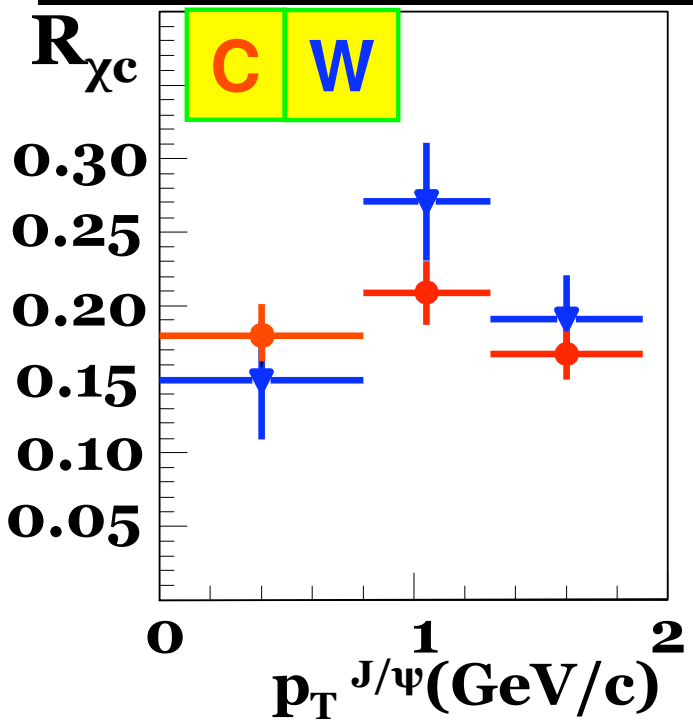


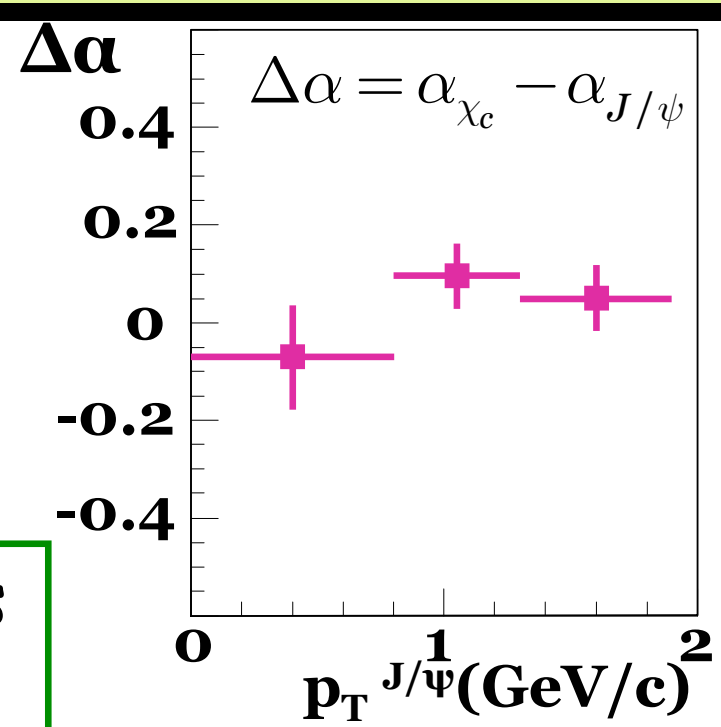
not clear experimental panorama



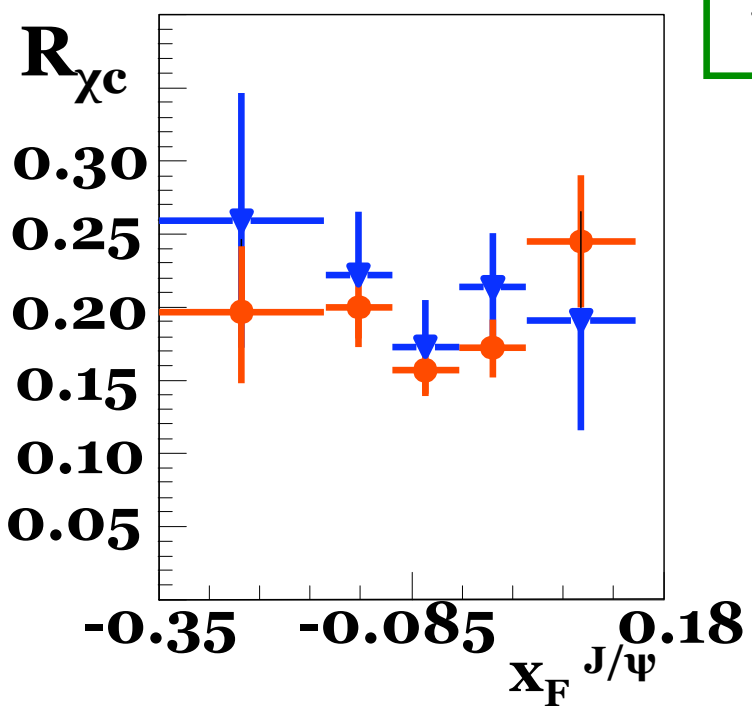
Phys. Rev: D79 012001,2009

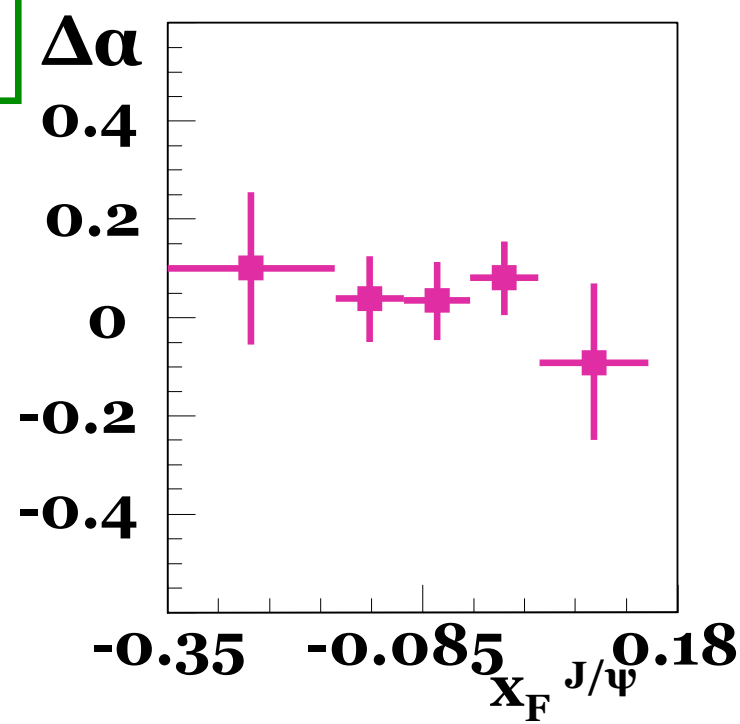
kinematic distributions of R_{χ_c} and nuclear suppression





All distributions compatible with flat distribution





Conclusions

J/ψ

Production vs p_T and x_F

Nuclear suppression

J/ψ polarization — all frames, all variables

→

- p_T broadening
- x_F: peak shift and width increase
- enhancement at negative x_F
- Longitudinal polarization

ψ' and χ_c

J/ψ feed-down

$\psi' \to J/\psi$ (6.8±0.4)%

$\chi_c \to J/\psi$ (18.8 ± 2.7)%

Production

~ flat wrt J/ψ