

Recent Charmonium Results from HERA-B

XV International Workshop on

Deep-Inelastic Scattering 2007

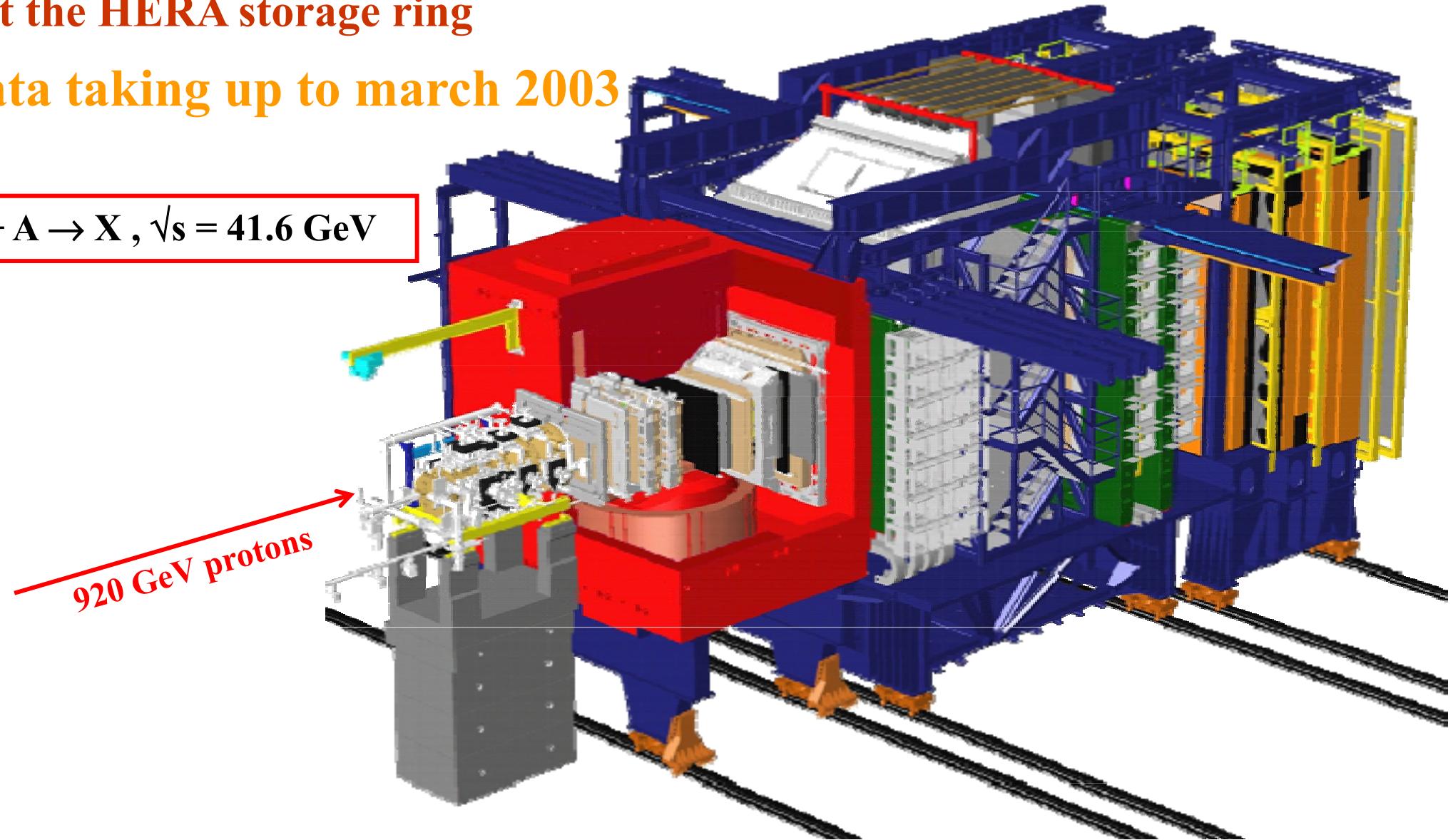
April 16 – 26 2007, Munich, Germany

Martin zur Nedden
Humboldt-Universität zu Berlin
for the *HERA-B Kollaboration*

The HERA-B Experiment

at the HERA storage ring
data taking up to march 2003

$p + A \rightarrow X, \sqrt{s} = 41.6 \text{ GeV}$



Contents

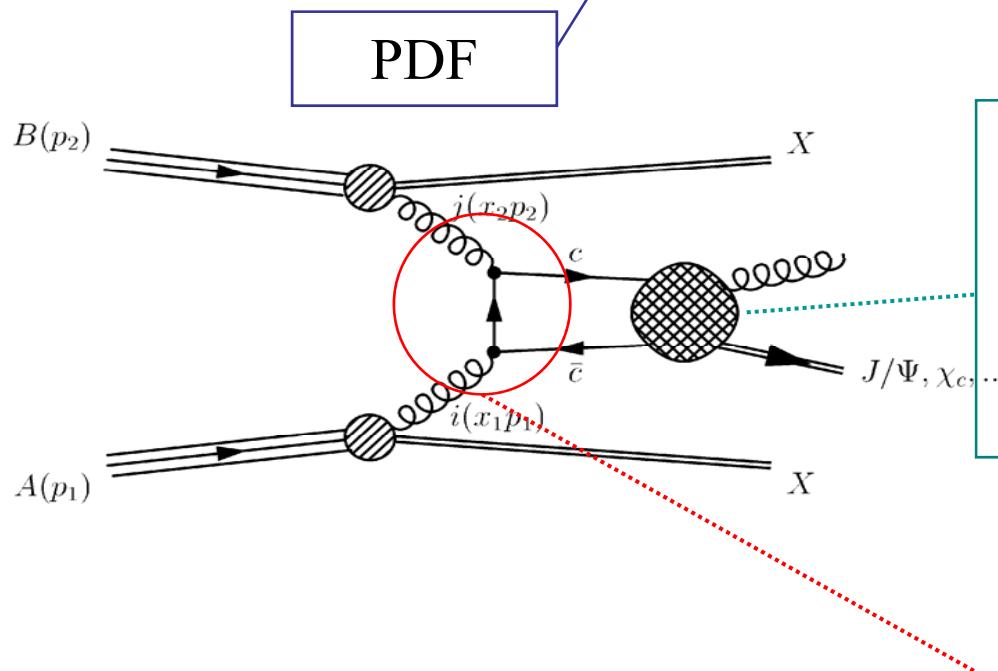
- Introduction
- HERA-B Detector
- Reference J/ψ -Production Cross Section
- Charmonium Production:
 - J/ψ : Kinematical Distributions
 - J/ψ : Nuclear Dependence
 - Polarisation Measurement
 - $\psi(2S)$ Production
 - χ_c Production

Part 1

- **Introduction**
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Proton-Nucleus Interaction

$$\sigma_{c\mathcal{H}} = \sum_{i,j} \int dx_1 dx_2 \underbrace{f_{i/A} f_{j/B}}_{\Lambda_{QCD}} \times \underbrace{\hat{\sigma}[ij \rightarrow (c\bar{c}[n] + X')]}_{m_c} \times \underbrace{O[c\bar{c} \rightarrow c\mathcal{H}]}_{m_c v} + O\left(\frac{\Lambda_{QCD}}{m_c^2}\right)$$



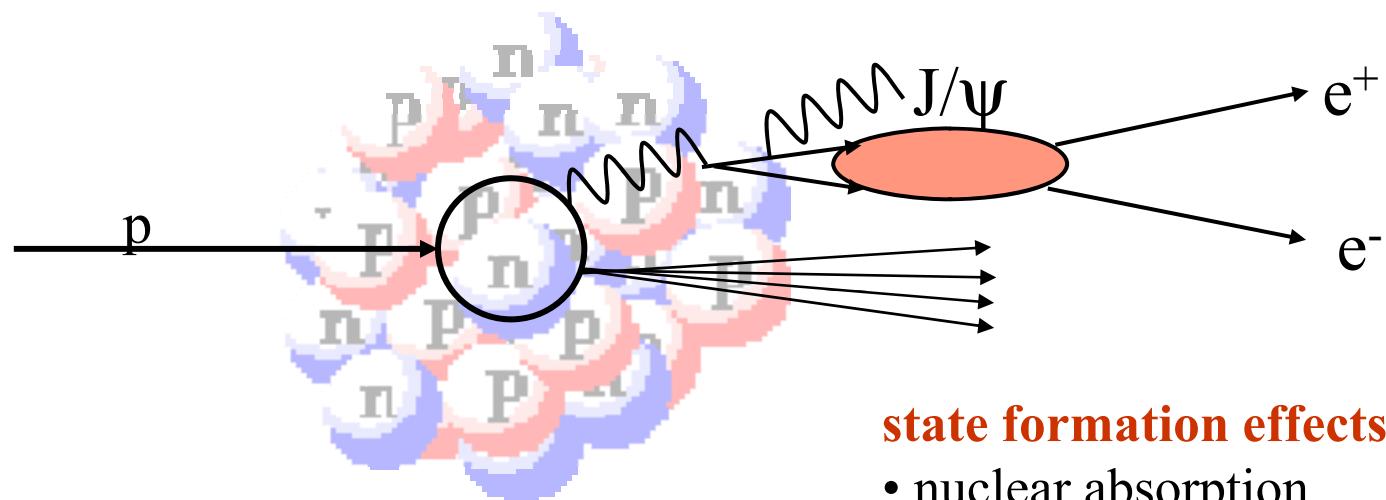
hadronization

long distance ($\sim 1/(m_c v)$) process
 → non-perturbative calculations +
 input from experiments

$q\bar{q}$ formation

short distance ($\sim 1/m_c$) / high momentum process
 → perturbative calculations

Study of Charmonium Suppression



initial state effects:

- shadowing (nuclear PDFs)
- parton energy loss
- intrinsic charm

state formation effects:

- nuclear absorption
- comover absorption
- multiple scattering + energy loss

HERA-B:

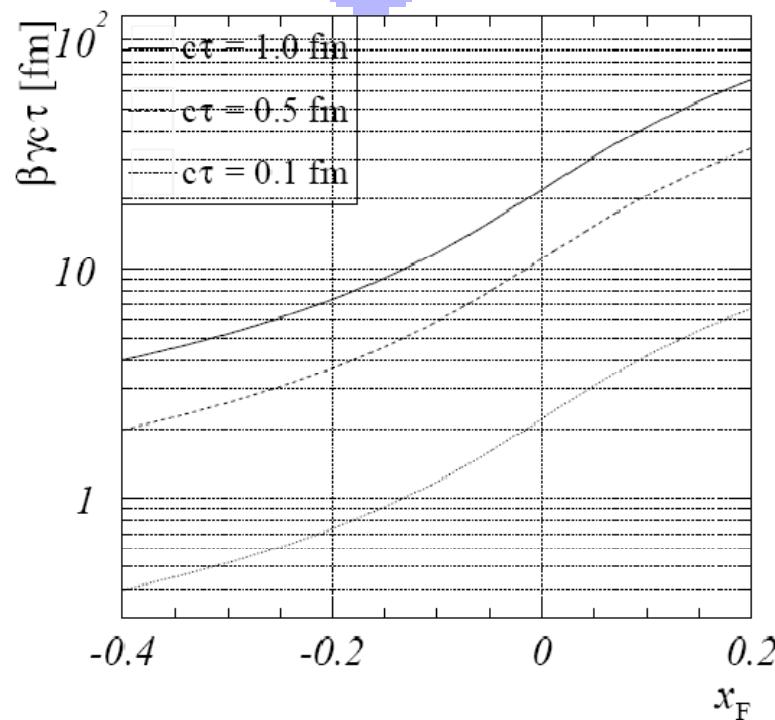
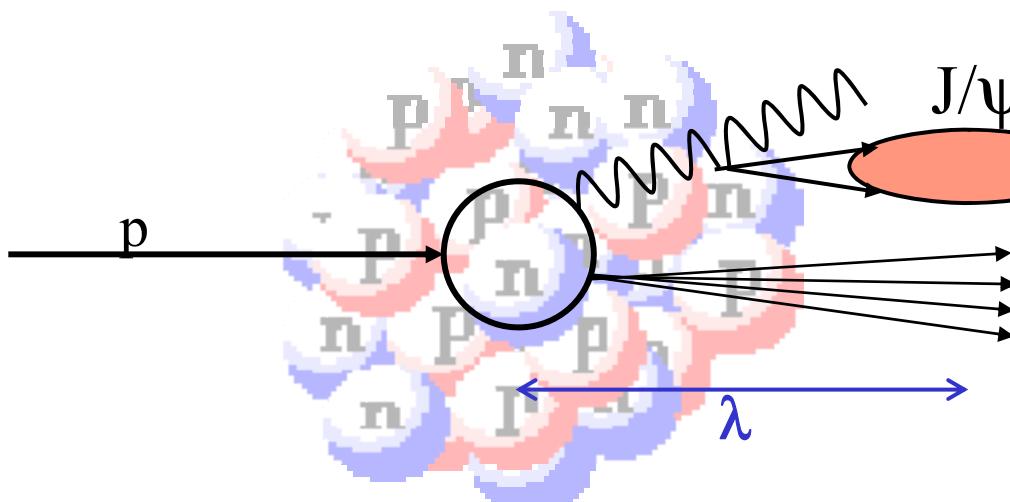
measurement of α using 2 wire materials:

$$\sigma_{cc} = \sigma_0 \cdot A^\alpha$$

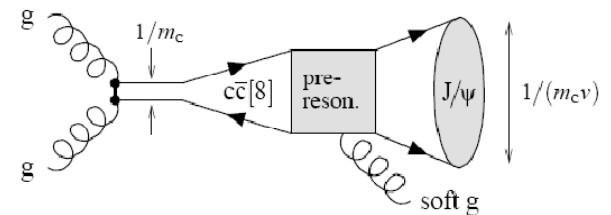
$\alpha \neq 1 \Rightarrow$ “suppression”

$$\alpha = \frac{\log\left(\frac{\sigma_2}{\sigma_1}\right)}{\log\left(\frac{A_2}{A_1}\right)} = \frac{\log\left(\frac{N_2}{N_1} \frac{L_1}{L_2} \frac{\epsilon_1}{\epsilon_2}\right)}{\log\left(\frac{A_2}{A_1}\right)}$$

x_F -Dependence of Nuclear Suppression



for $c\tau = 0.5 \text{ fm}$	
x_F	$\lambda [\text{fm}]$
0.2	30
0	10
-0.2	4



formation time and length:

$$\lambda(x_F) = \beta \gamma c \tau$$

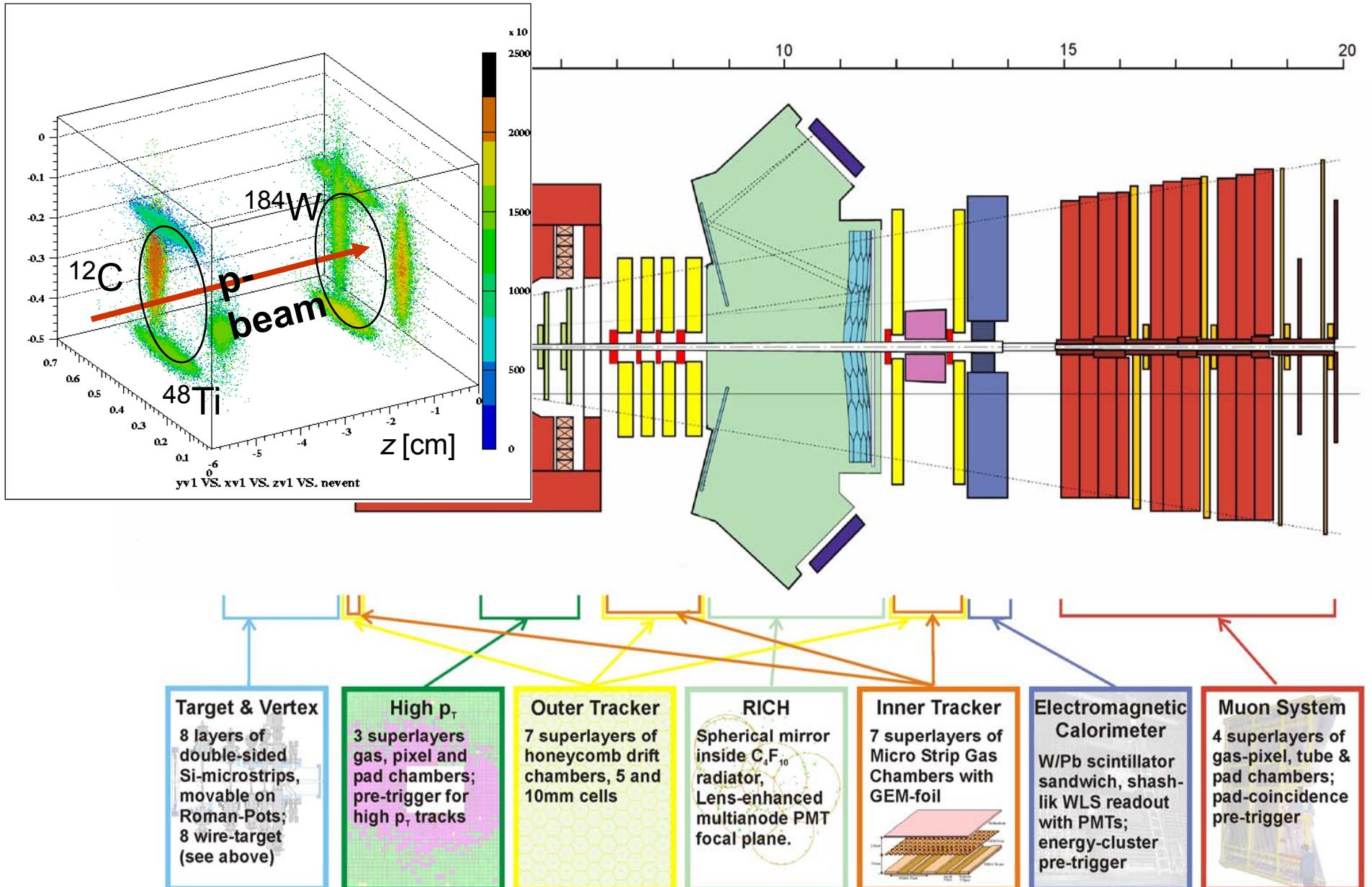
$\gamma = \gamma(x_F)$ boost of J/ψ w.r.t. nucleus

Nuclear radius:
 $C \sim 3 \text{ fm}$.
 $W \sim 8 \text{ fm}$.

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The HERA-B Detector



Main Data Samples

- **150 M di-lepton trigger events** (e^+e^- / $\mu^+\mu^-$ triggers)

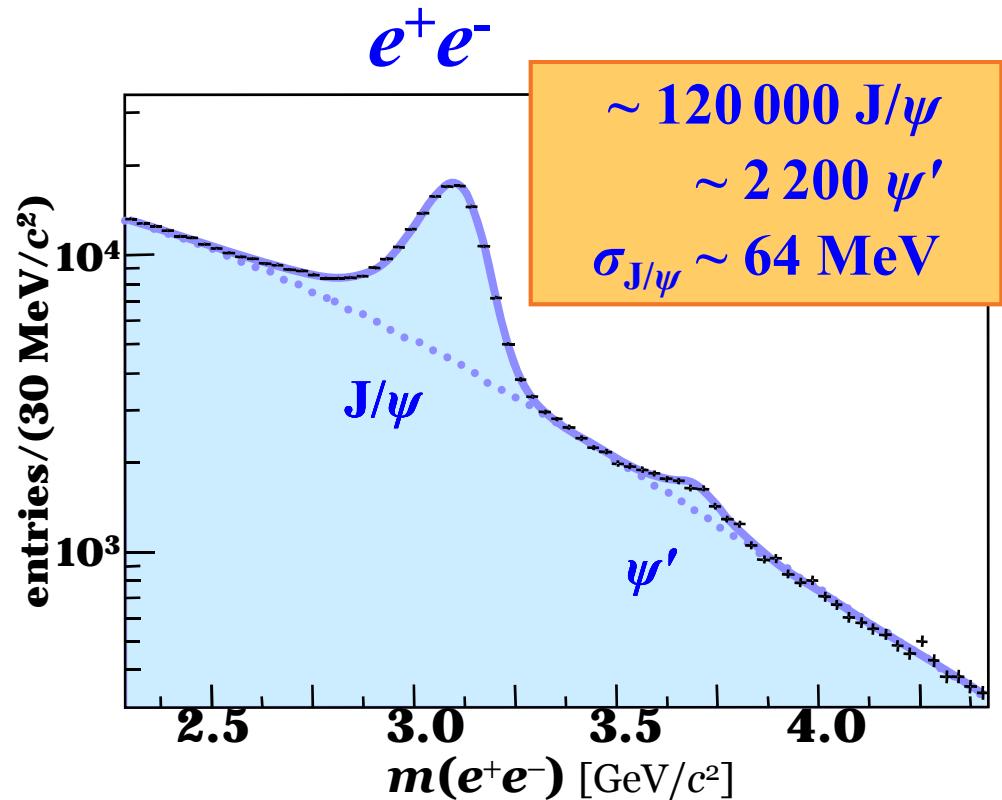
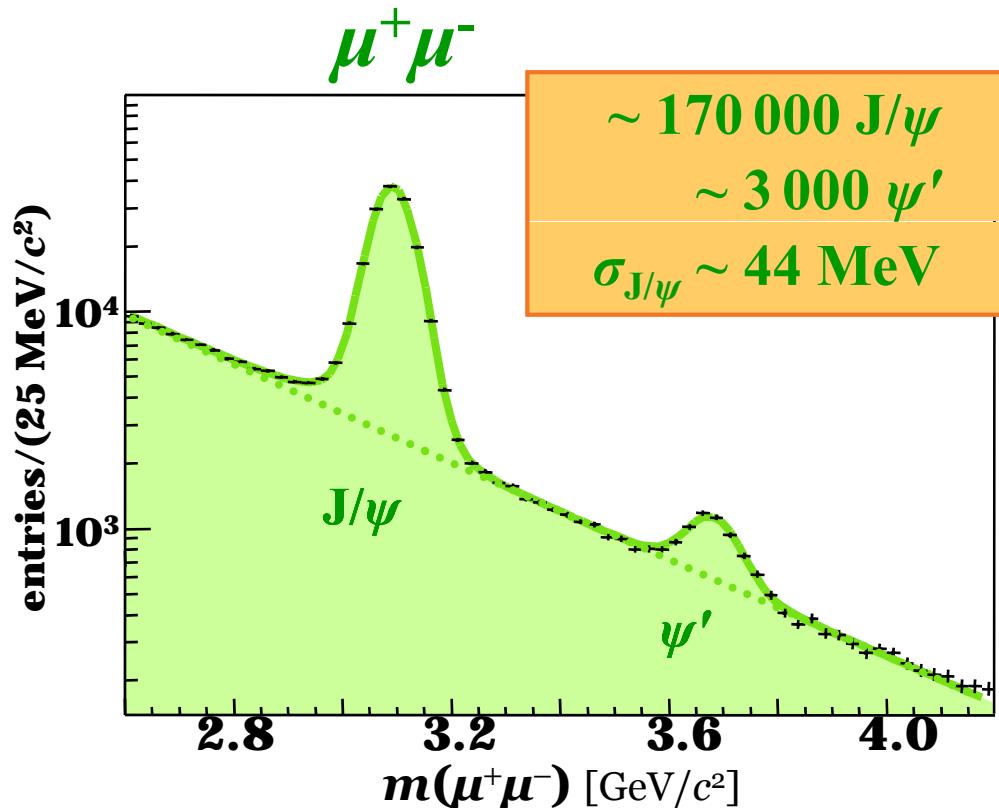
- $\sim 300\,000 J/\psi$ (>1000 per hour)
- $\sim 15\,000 \chi_{c1}^+ \chi_{c2}^-$
- $\sim 5\,000 \psi(2S)$

- **210 M minimum bias events**

→ 1000 ev./s > 1TB/day

Three target materials:
pC, pW and pTi collisions

absolute cross section measurements from **di-lepton triggered data** need independent **reference cross section**

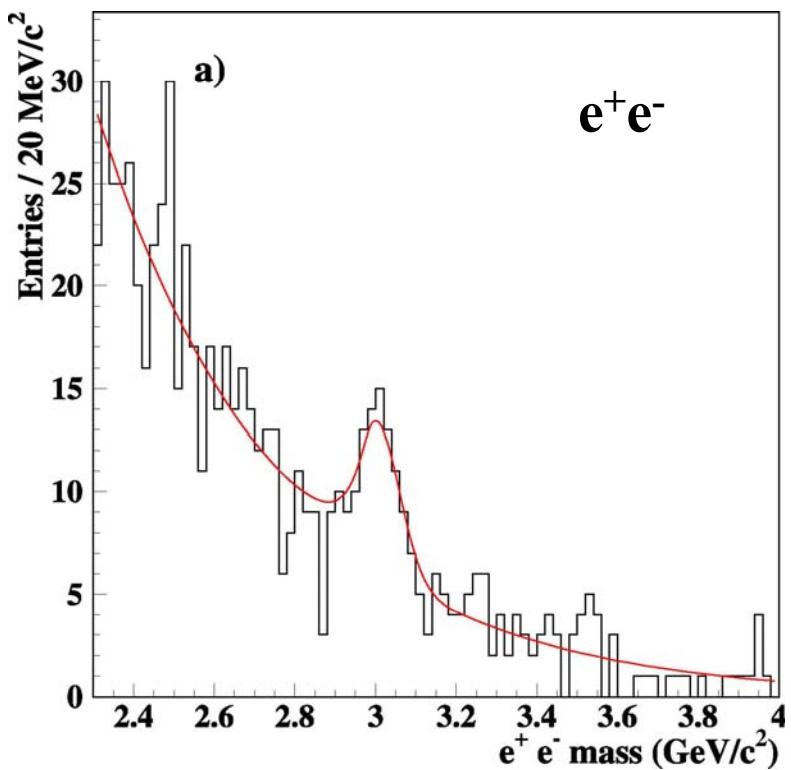
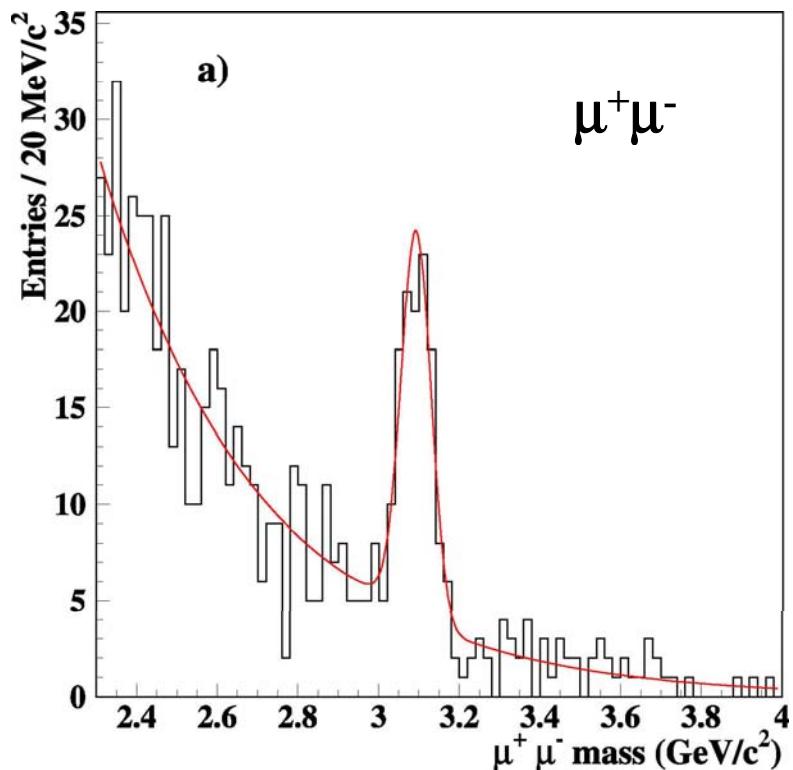


Part 3

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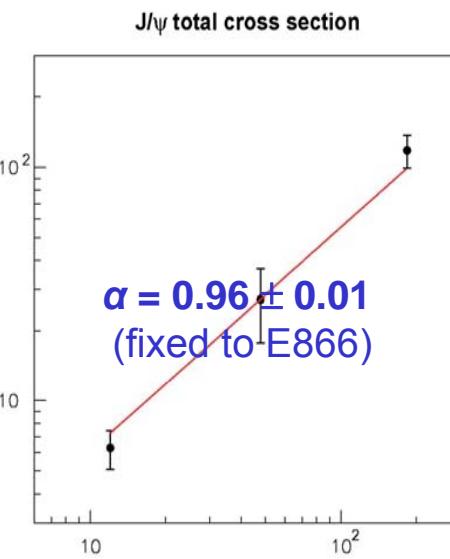
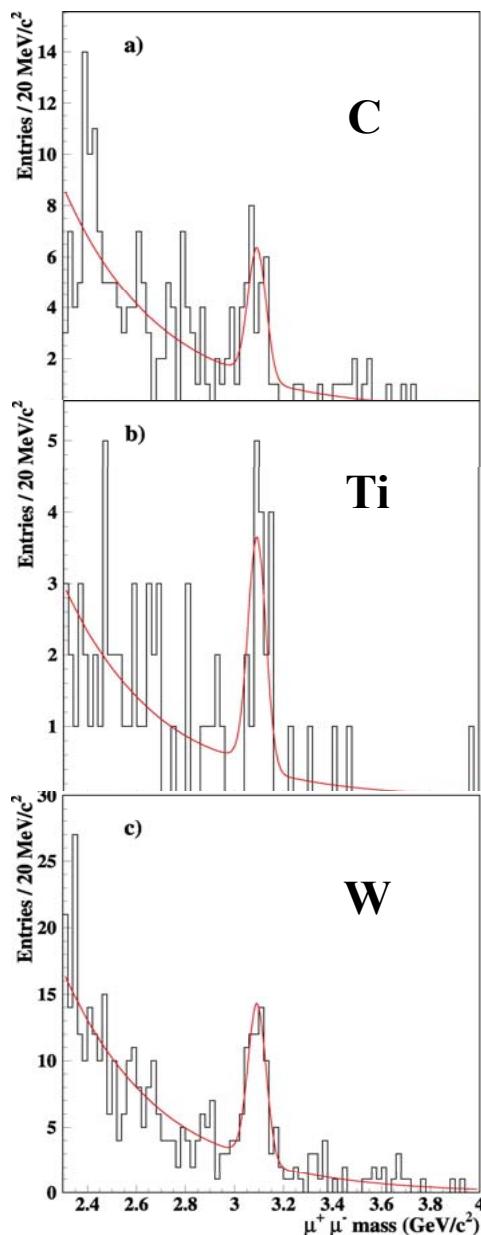
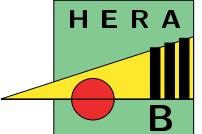
J/ ψ Production Cross Section from Minimum Bias data

important for **cross section normalisation** of all di-lepton triggered data based measurements



- independent data sample
- efficiency and luminosity well understood
- ⇒ systematic uncertainties small (usually dominant)

J/ ψ (MinB): A-Dependence and Results



$$\sigma_{J/\psi} = \frac{N_{J/\psi}}{\epsilon_{J/\psi} \cdot BR(J/\psi \rightarrow \mu^+ \mu^-) \cdot \sum_i A_i^\alpha L_i}$$

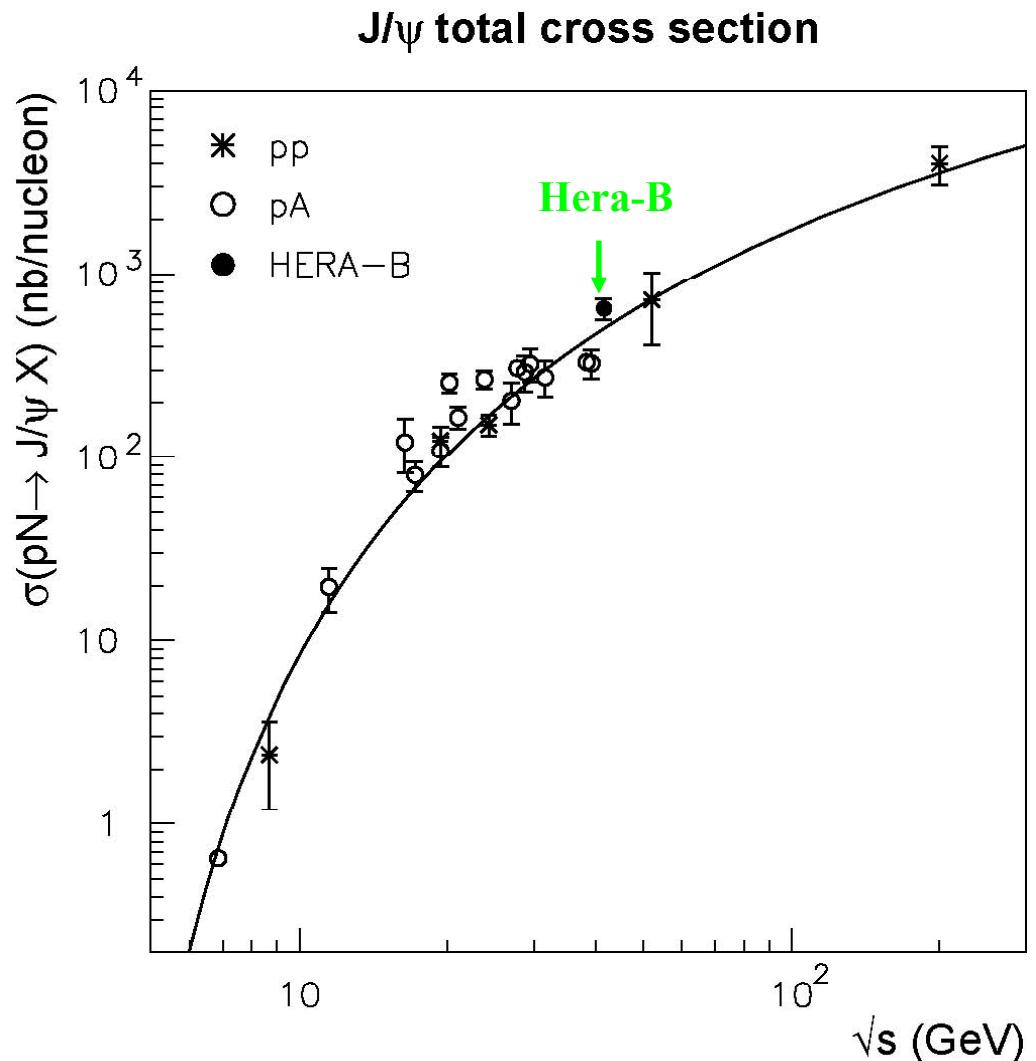
results:

A

$$\sigma_{pN}^{J/\psi} = 663 \pm 74 \pm 46 \text{ nb/nucleon.}$$

$$\left. \frac{d\sigma_{pN}^{J/\psi}}{dy} \right|_{y=0} = 392 \pm 44 \pm 27 \text{ nb/nucleon.}$$

[Phys.Lett.B638(2006)407]



reference cross section is extracted by NRQCD
inspired fit including all available data

[F. Maltoni, hep-ph/0003003]

fit results at HERA-B energy

$\sqrt{s} = 41.6$ GeV:

$$\sigma_{J/\psi} = (502 \pm 44) \text{ nb/nucleon ,}$$

$$\sigma_{\psi(2S)} = (65 \pm 11) \text{ nb/nucleon ,}$$

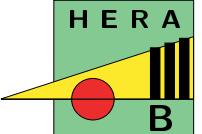
$$R_\psi = (0.130 \pm 0.019)$$

$$\text{where } R_\psi = \sigma_{\psi(2S)} / \sigma_{J/\psi}$$

Part 4a

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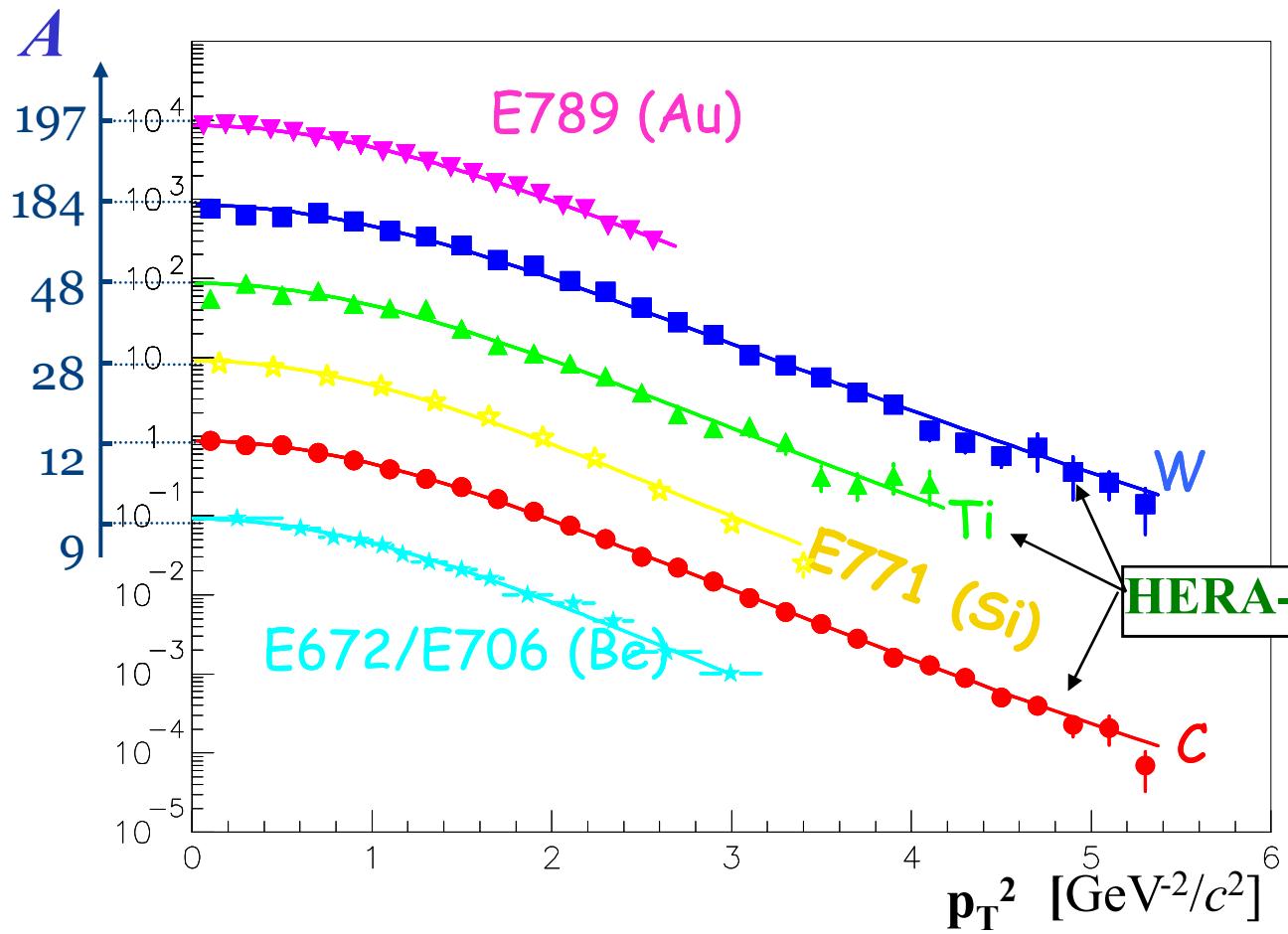
J/ ψ p_T Distributions (Nuclear Dependence)



preliminary data (di-electron only), compared with $p\text{-}A$ results at similar energy ($\sqrt{s} = 38.8$ GeV)

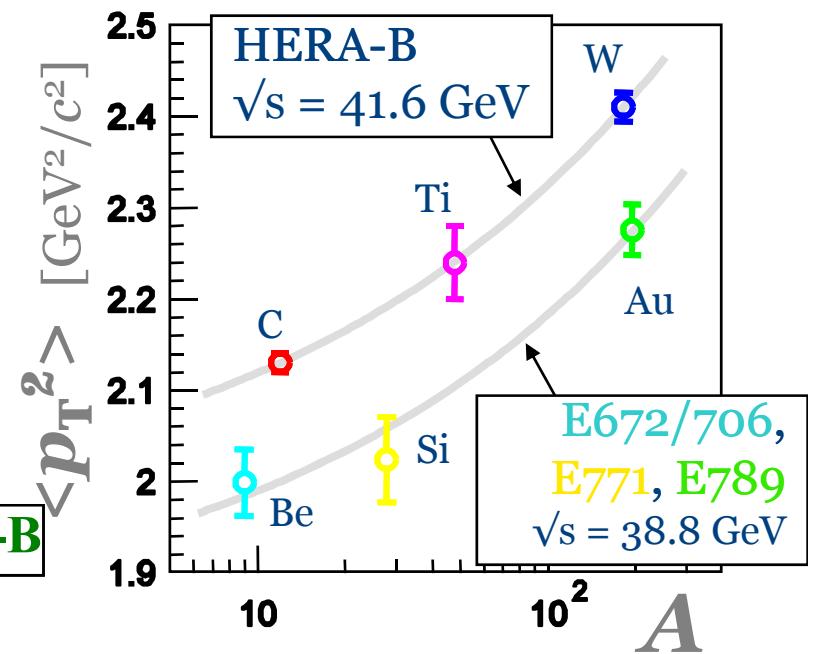
$$\frac{1}{s} \frac{ds}{dp_T^2}$$

→ Kinematic range enlarged



standard fit:

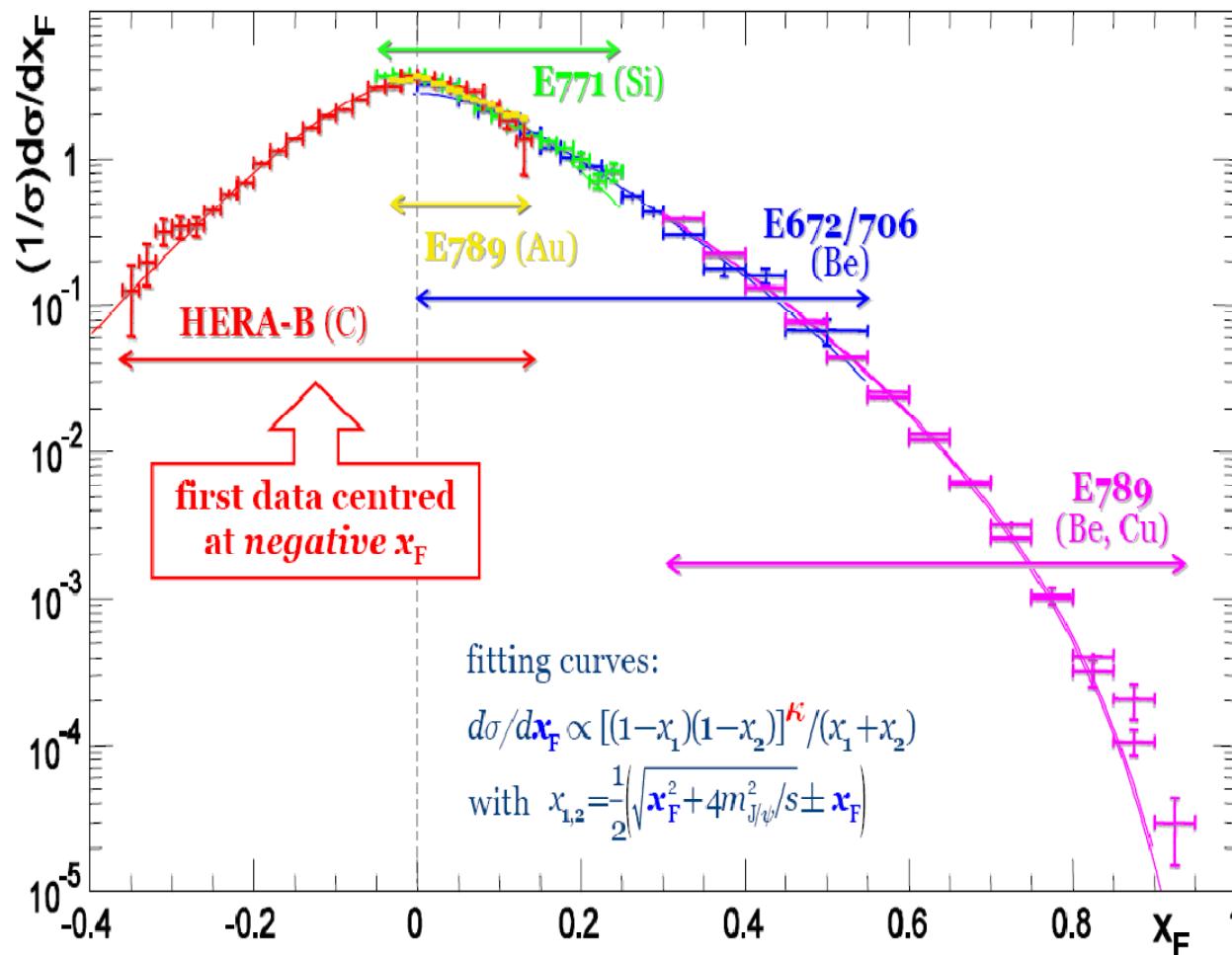
$$\frac{d\sigma}{dp_T^2} = A \left[1 + \left(\frac{35\pi}{256} \frac{p_T}{\langle p_T \rangle} \right)^2 \right]^{-6}$$



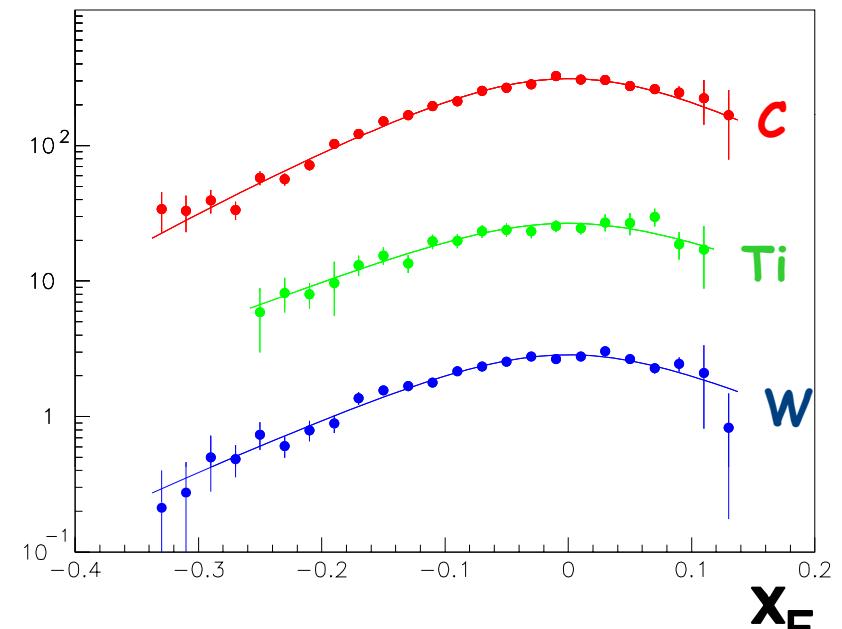
Increase of $\langle p_T^2 \rangle$ with cms energy and with A .
 → Consistent with a linear dependence on the nuclear path length.

J/ ψ x_F - Distribution

Preliminary data (e^+e^- C sample), compared with p -A results at 38.8 GeV



HERA-B results per target Material:



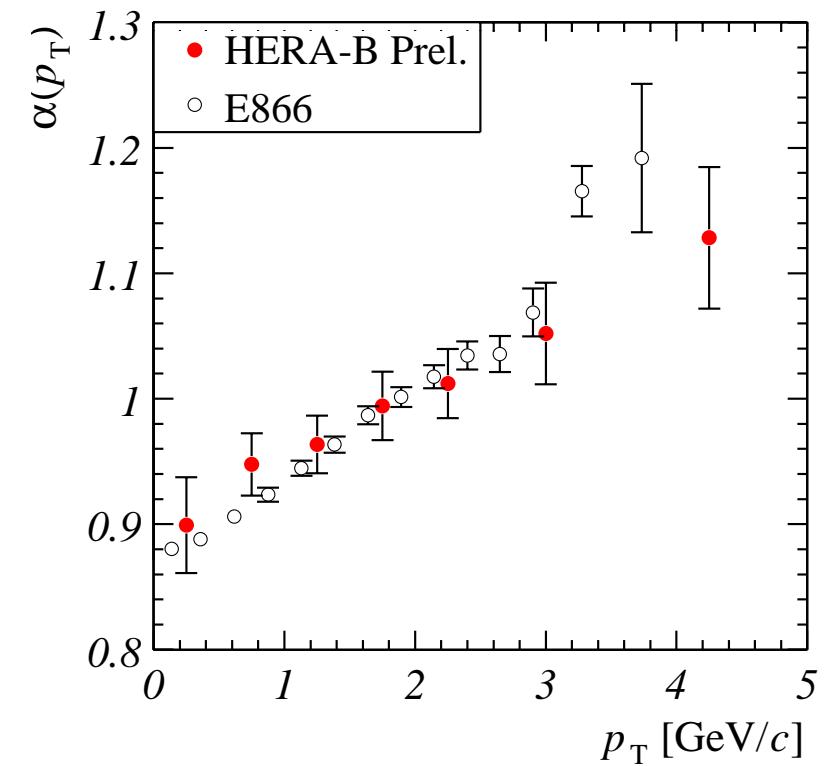
Electron channel: compared with p-A results ($\sqrt{s}=38.8$ GeV) agreement with muon channel in all distributions.

J/ ψ A-Dependence

Test of **charmonium production models in nuclear matter**
 (NRQCD + initial/final state interactions in nucleus)

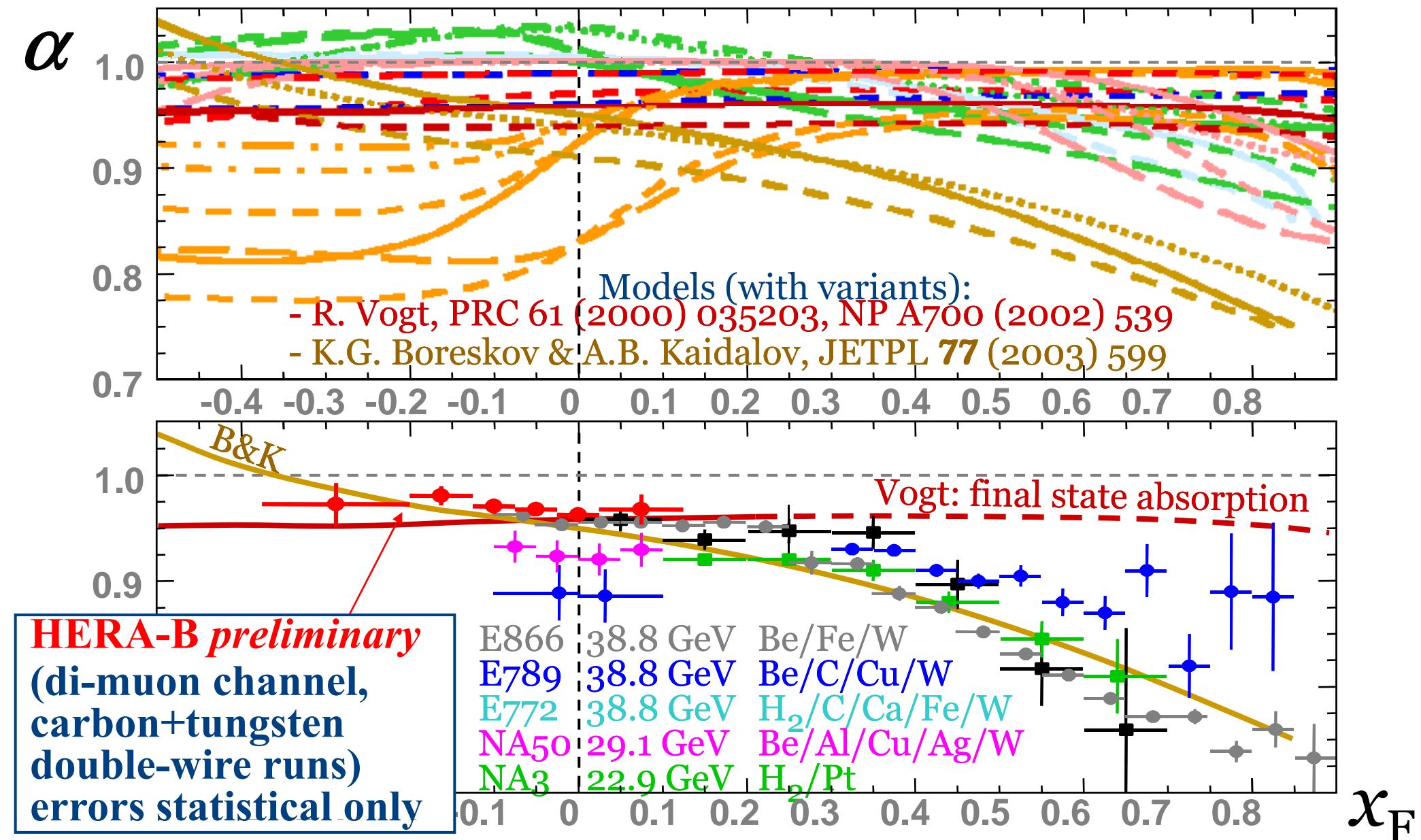
$$\sigma_{\text{pA}} = \sigma_{\text{pN}} \cdot A^{\alpha}; \quad \sigma = N / \varepsilon L$$

- $\alpha < 1$: charmonium suppression by nuclear effects
- **HERA-B**: extract α from runs with two target wires simultaneously
 (carbon: $A=12$, tungsten: $A=184$)
- Results from **full $\mu^+\mu^-$ sample**. Only statistical uncertainties. **Similar results** from the e^+e^- sample.

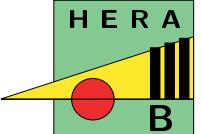


- P_T broadening effect as seen by E866 experiment
- Previous result of FNAL E866 **extended to $x_F = -0.35$**

J/ ψ A-Dependence



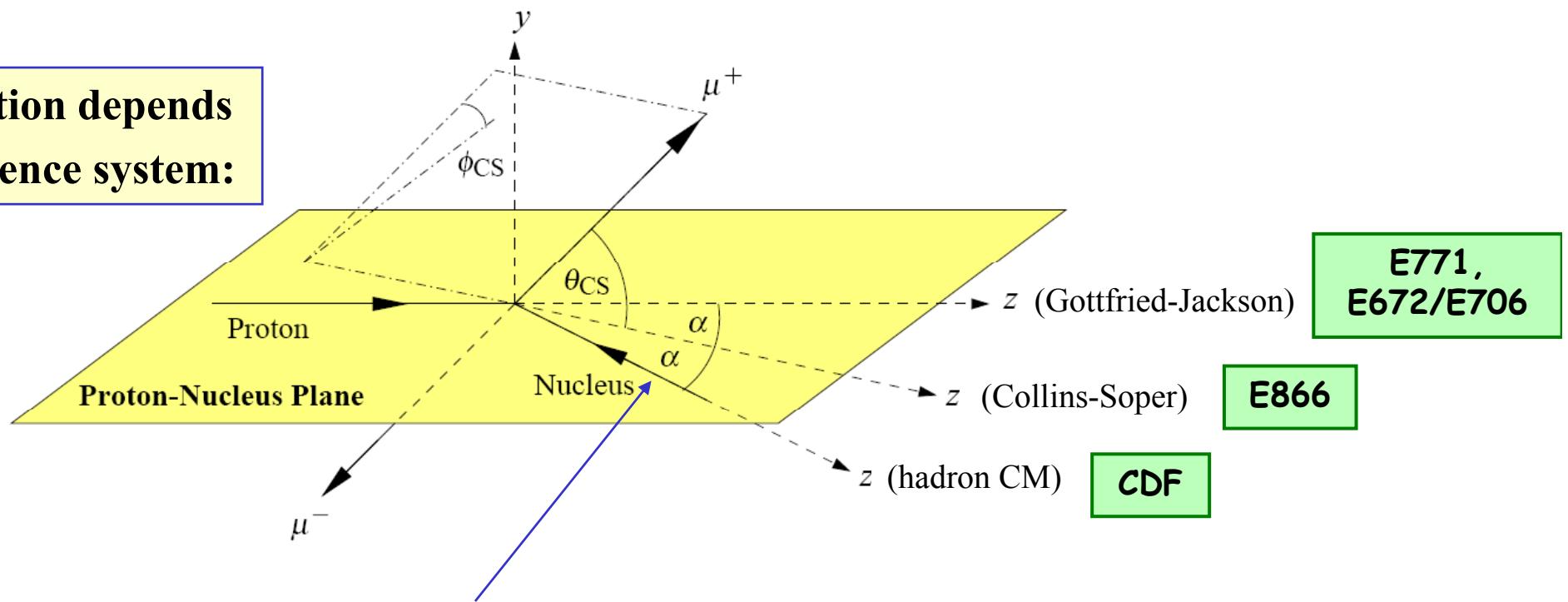
J/ψ Polarisation



$$\frac{1}{\sigma} \frac{d\sigma}{d\Omega} = \frac{3}{4\pi(3 + \lambda_\vartheta)} \left\{ 1 + \lambda_\vartheta \cos^2 \vartheta + \lambda_{\vartheta\varphi} \sin 2\vartheta \sin \varphi + \lambda_\varphi \sin^2 \vartheta \cos 2\varphi \right\}$$

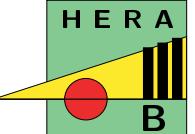
usually only $\lambda = \lambda_\vartheta$ is given

polarisation depends
on reference system:

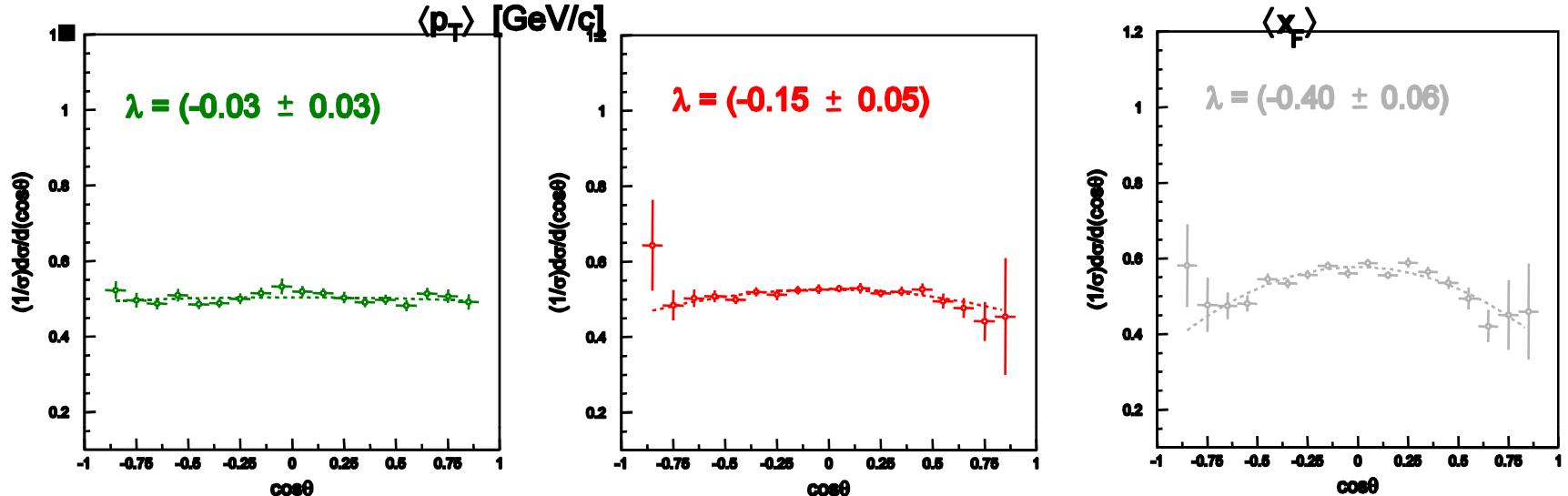
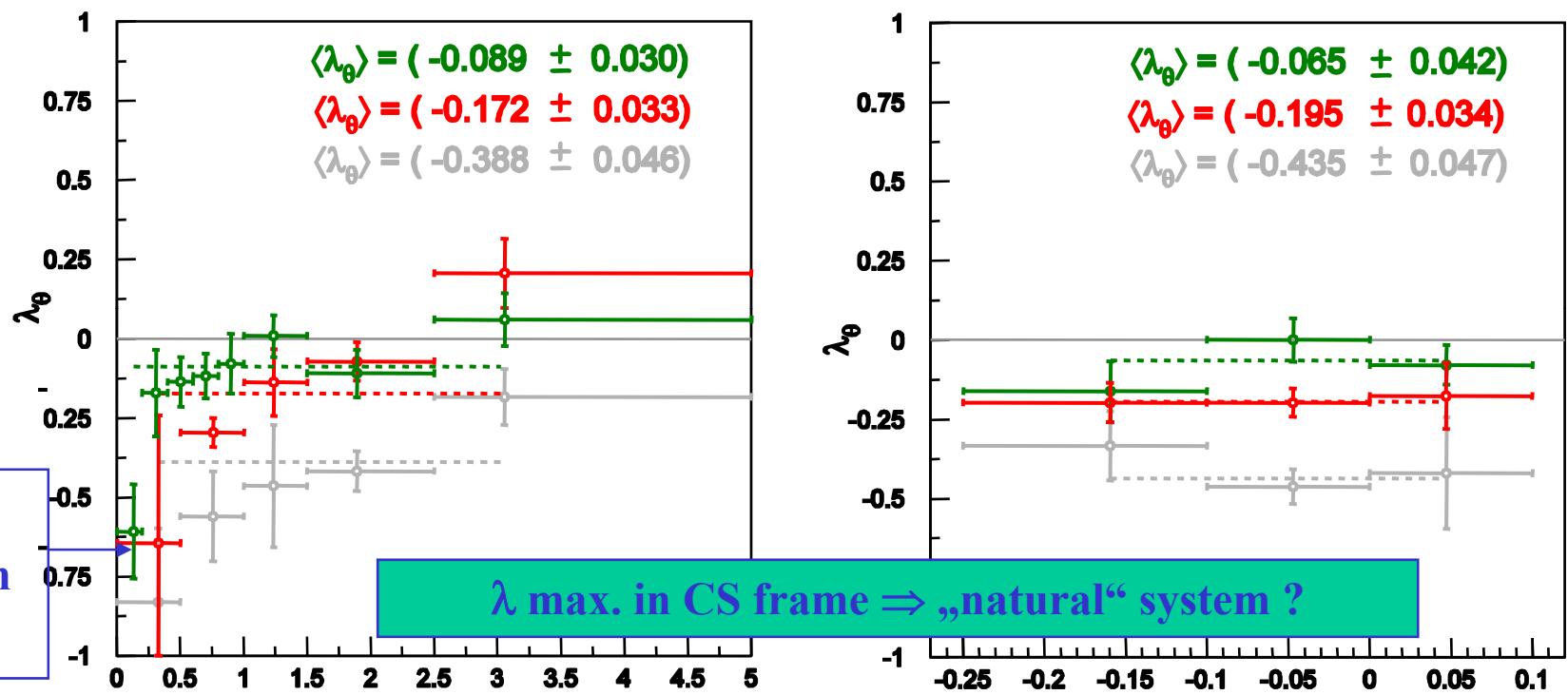


$\tan \alpha = p_T / M_{J/\psi} \Rightarrow$ only for $p_T \neq 0$ are the systems different

Preliminary Polarisation Results

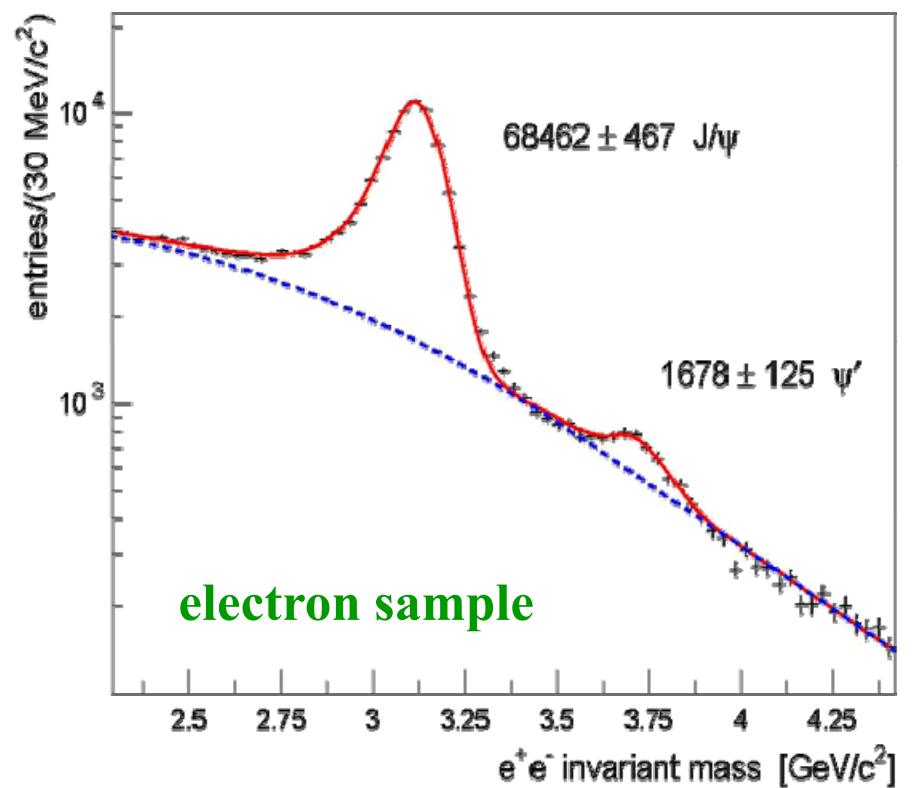
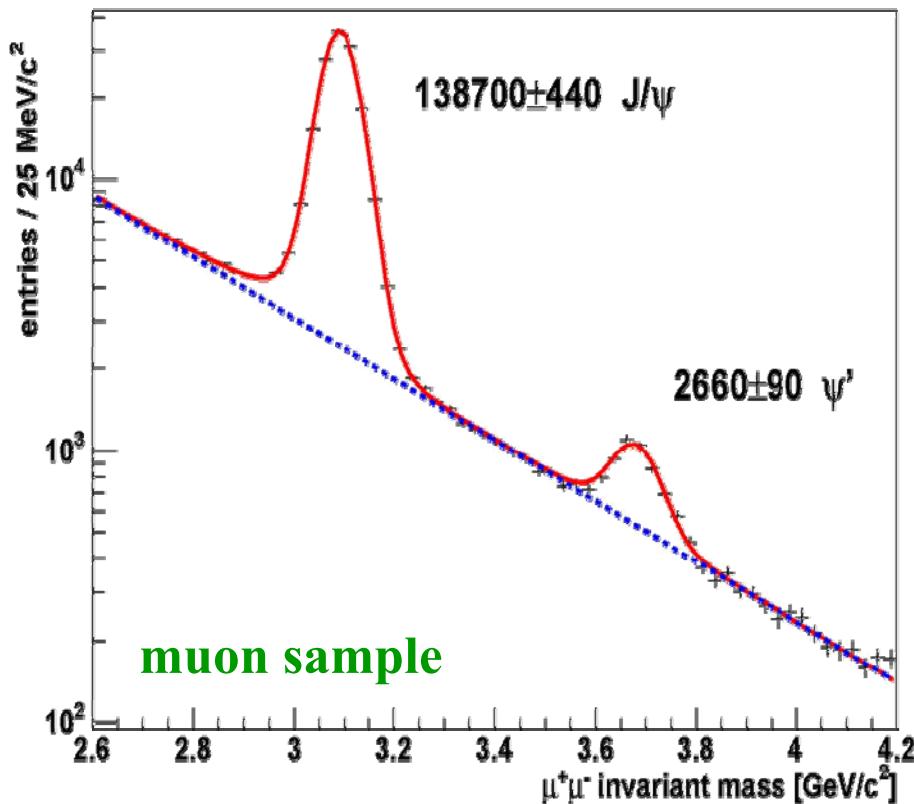


HCM
GJ
CS



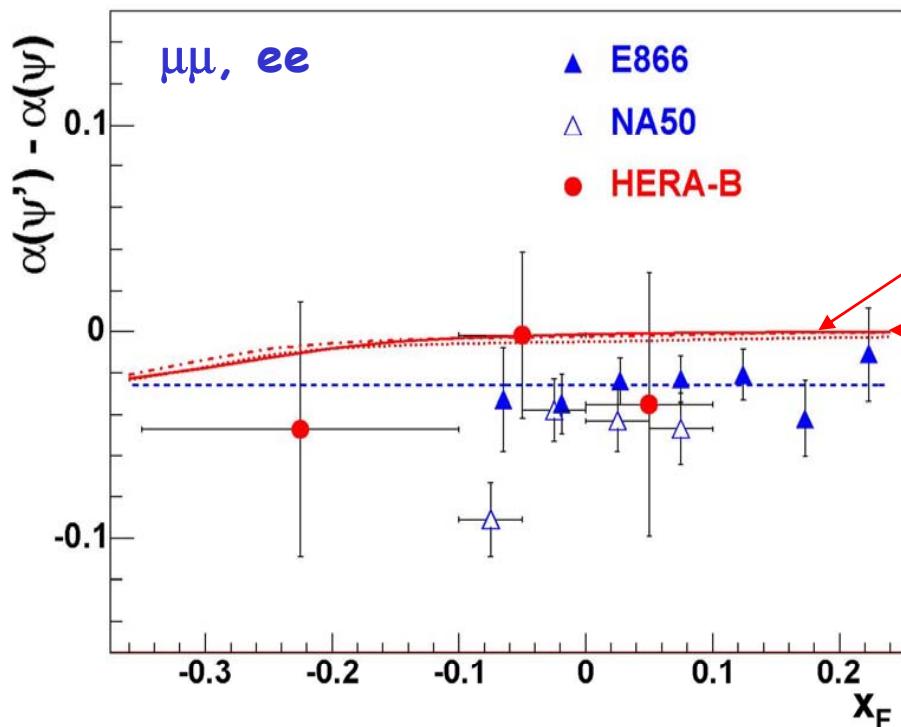
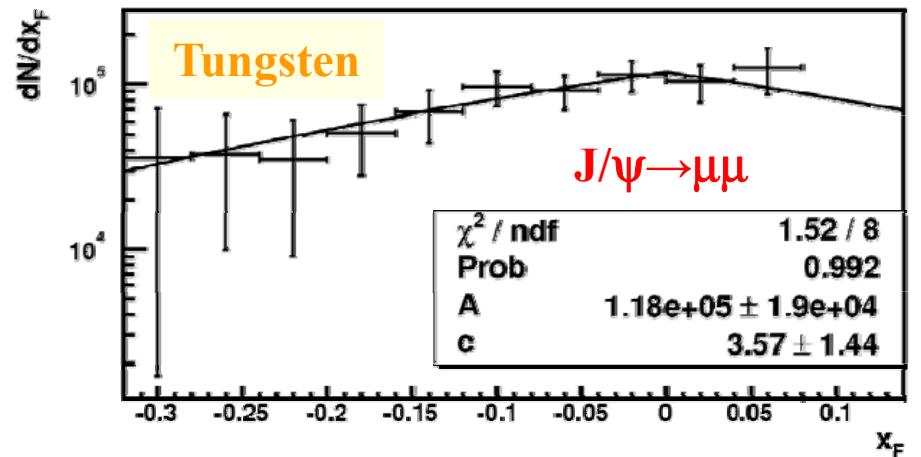
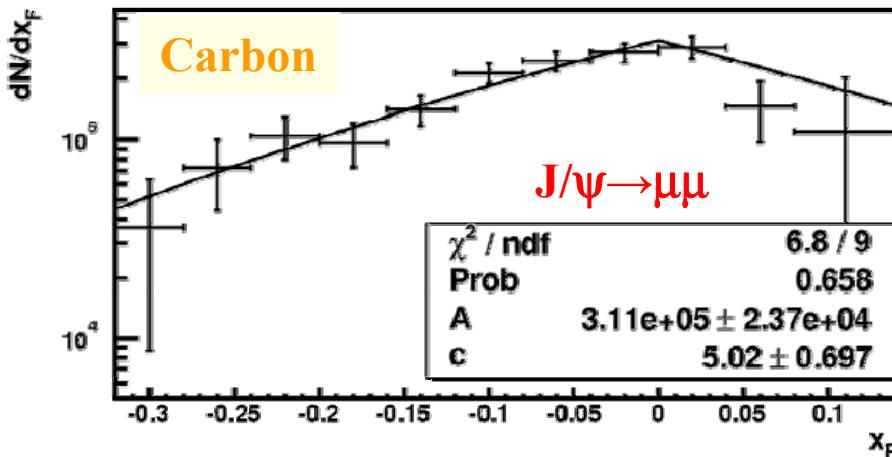
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$\psi'/J/\psi$ Production Ratio



$$\frac{BR(\psi' \rightarrow l^+l^-) \cdot \sigma_{\psi'}}{BR(J/\psi \rightarrow l^+l^-) \cdot \sigma_{J/\psi}} = \frac{N_{\psi'}}{N_{J/\psi}} \frac{\epsilon_{J/\psi}}{\epsilon_{\psi'}}$$

Kinematical Distributions



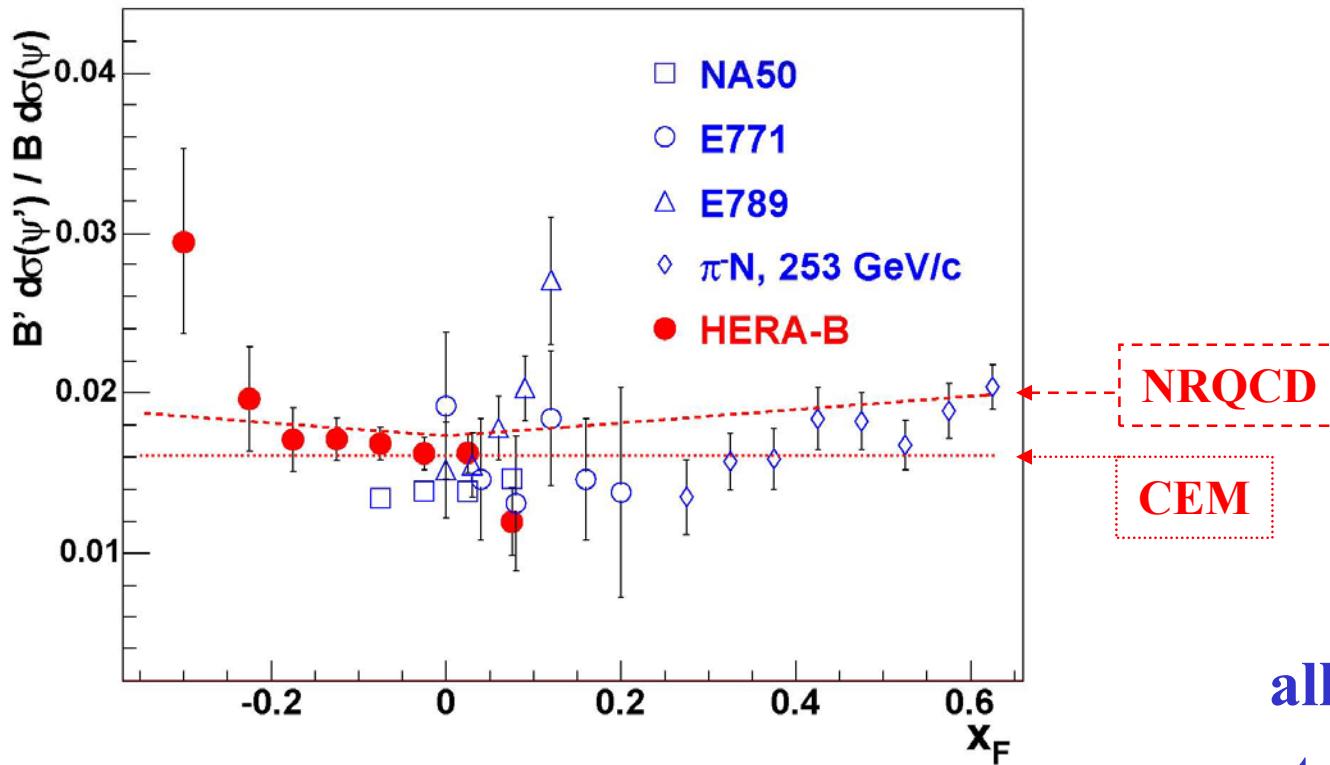
A-dependence: $\Delta\alpha(x_F) = \alpha' - \alpha$

CEM for color-1 nuclear absorption

NRQCD for color-1 & -8 nuclear absorption

fit with const: $\Delta\alpha(E866) = -0.026 \pm 0.005$

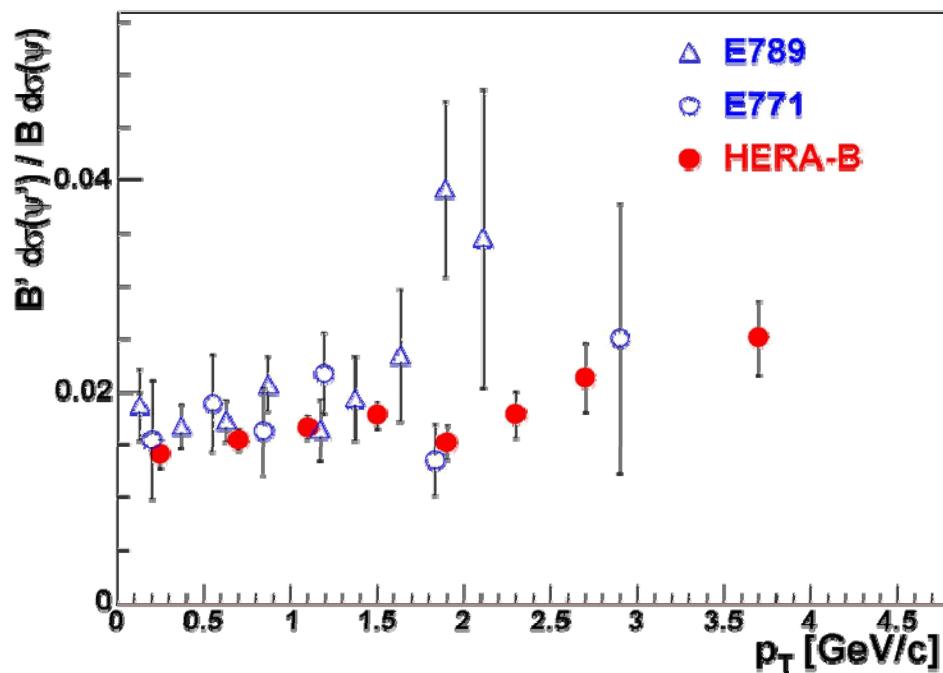
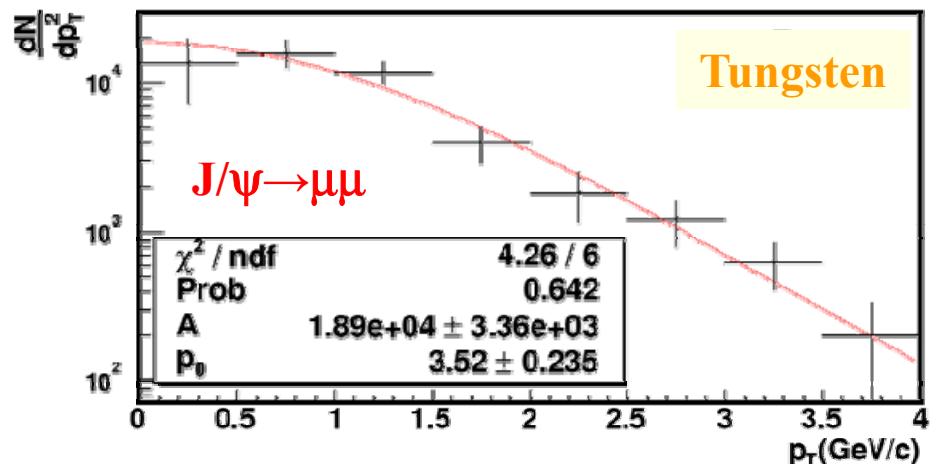
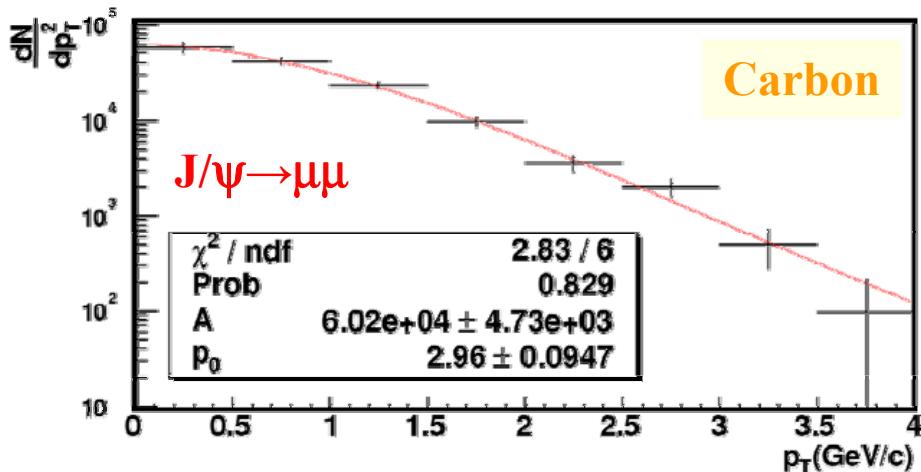
all consistent with no x_F dependence.
average of E866 and NA50 is used:
 $\Delta\alpha(E866, NA50) = -0.030 \pm 0.004$



all targets included,
correct for nuclear effects with
 $\Delta\alpha(E866, \text{NA50})$

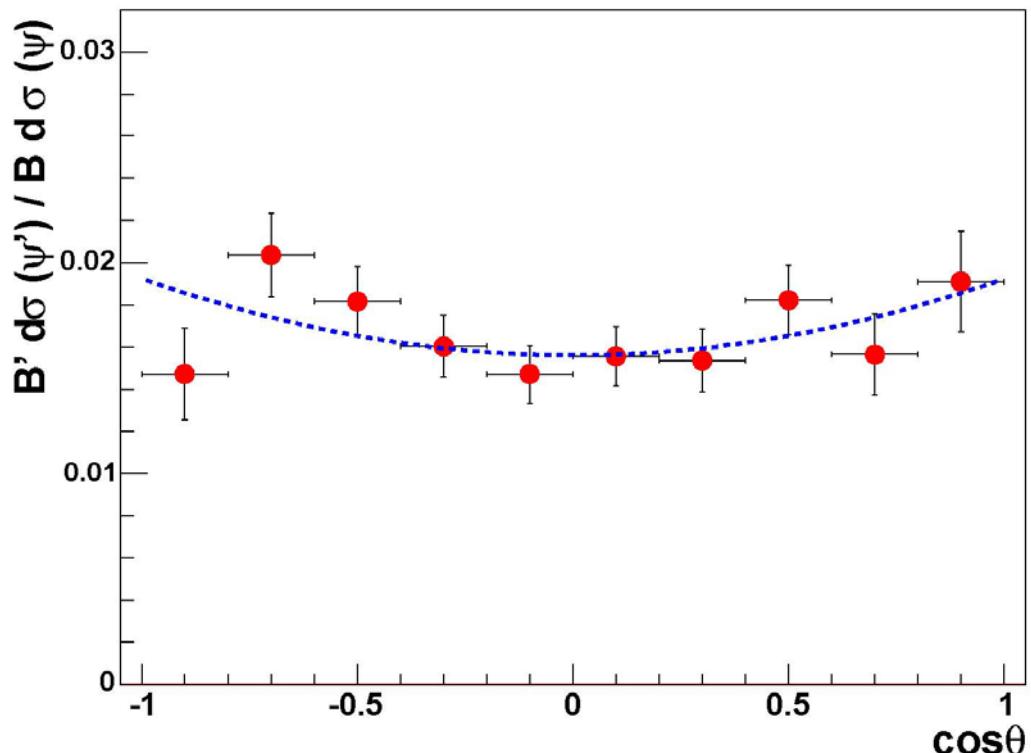
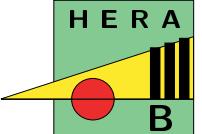
data are consistent with both models
(and with no x_F dependence)

ψ' production: p_T distributions



\Rightarrow tendency for a wider p_T distribution of ψ'
(increasing with A?)

→' Polarisation Measurement



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

$$\frac{B' d\sigma'/d\cos\theta}{B d\sigma/d\cos\theta} \propto \frac{1 + \lambda' \cos^2 \theta}{1 + \lambda \cos^2 \theta}$$

result of

$$\Delta\lambda = \lambda' - \lambda = 0.23 \pm 0.17$$

compatible with **no polarisation** difference

Production Ratio $\psi' / J/\psi$

$$B' \sigma' / B \sigma \text{ (C)} = 0.0163 \pm 0.0006 \pm 0.0004,$$

$$B' \sigma' / B \sigma \text{ (Ti)} = 0.0199 \pm 0.0024 \pm 0.0005,$$

$$B' \sigma' / B \sigma \text{ (W)} = 0.0162 \pm 0.0010 \pm 0.0004,$$

$$\frac{B' \sigma_A(\psi')}{B \sigma_A(\psi)} = R_{1\psi'} \cdot A^{\Delta \alpha}$$

$$R_{1\psi'} = 0.0183 \pm 0.0003$$

$$\Delta \alpha = -0.029 \pm 0.004$$

in addition: $\mu\mu$ and ee measurements yield:

Constraint on the double ratio
(test of lepton universality):

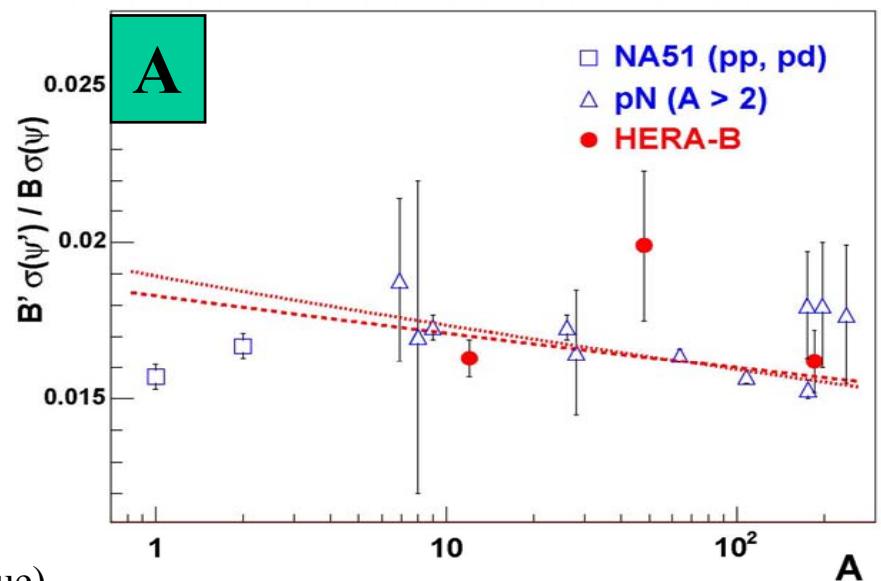
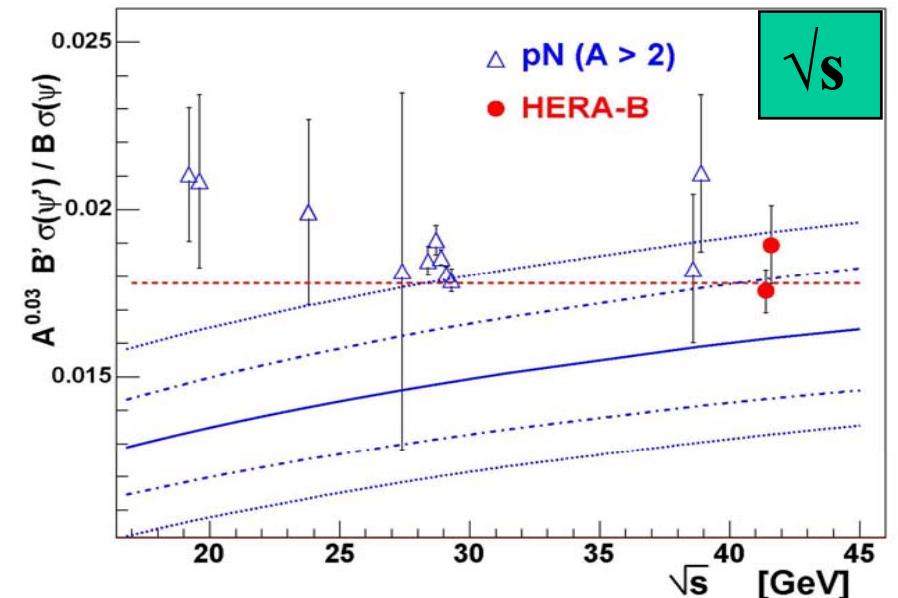
$$R_{\psi'}(\mu) / R_{\psi'}(e) = 1.00 \pm 0.08 \pm 0.04$$

current PDG avg.: 1.03 ± 0.12

\Rightarrow improvement of $B'(\mu)$:

$$B'(\mu)_{HERA-B} = (0.75 \pm 0.07 \pm 0.03)\%$$

(better than current PDG value)



ψ' Production

Combined results ($e^+e^- + \mu^+\mu^-$):

$$r_{y\psi'} = \frac{B_{y\psi'} \otimes 1^{+1-} s_{y\psi'}}{B_{J/\psi} \otimes 1^{+1-} s_{J/\psi}} = \begin{array}{l} \textcolor{red}{1.63 \pm 0.08 \% \text{(C)}} \\ \textcolor{magenta}{1.99 \pm 0.26 \% \text{(Ti)}} \\ \textcolor{blue}{1.62 \pm 0.11 \% \text{(W)}} \end{array}$$

- ψ' cross section measurement relative to J/ψ

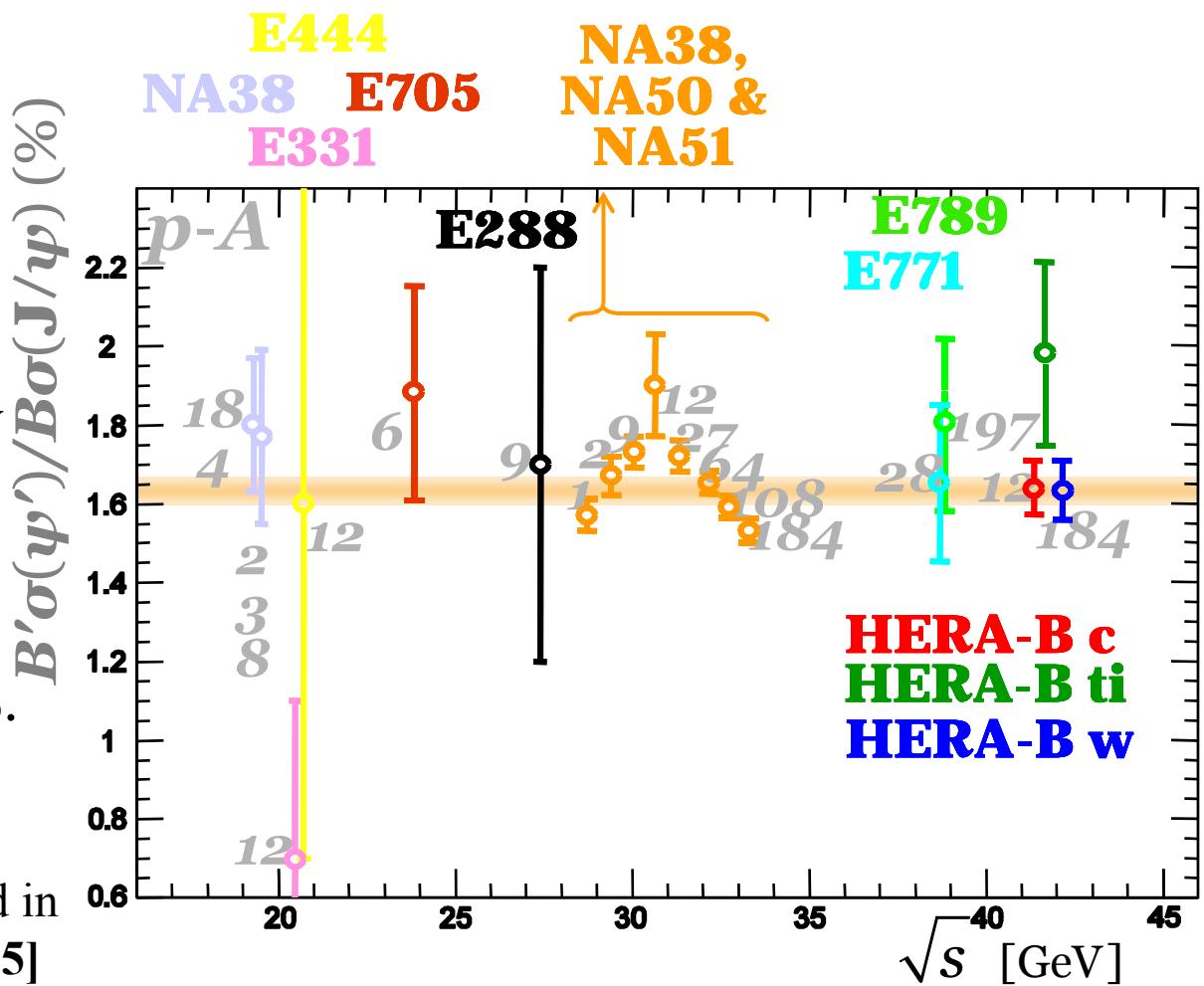
→ reduction of systematic uncertainties

- No dependence on cms energy and kinematics

except for Na38/50/51.

All results consistent within 4%.

HERA-B result published in
[Eur.Phys.J.C49(2006)545]



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χ_c Production

selection:

$$\begin{array}{c} \chi_c \rightarrow J/\psi \gamma \\ \downarrow \\ \rightarrow l^+ l^- \end{array}$$

measurement:

- fraction of J/ψ 's from χ_c :

$$R_{\chi_c} = \frac{\sum_{i=1}^2 \sigma_{\chi_{ci}} \cdot BR(\chi_{ci} \rightarrow J/\psi \gamma)}{\sigma_{J/\psi}} = \frac{N_{\chi_c}}{N_{J/\psi}} \cdot \frac{\epsilon_{J/\psi}}{\epsilon_{\chi_c} \epsilon_\gamma}$$

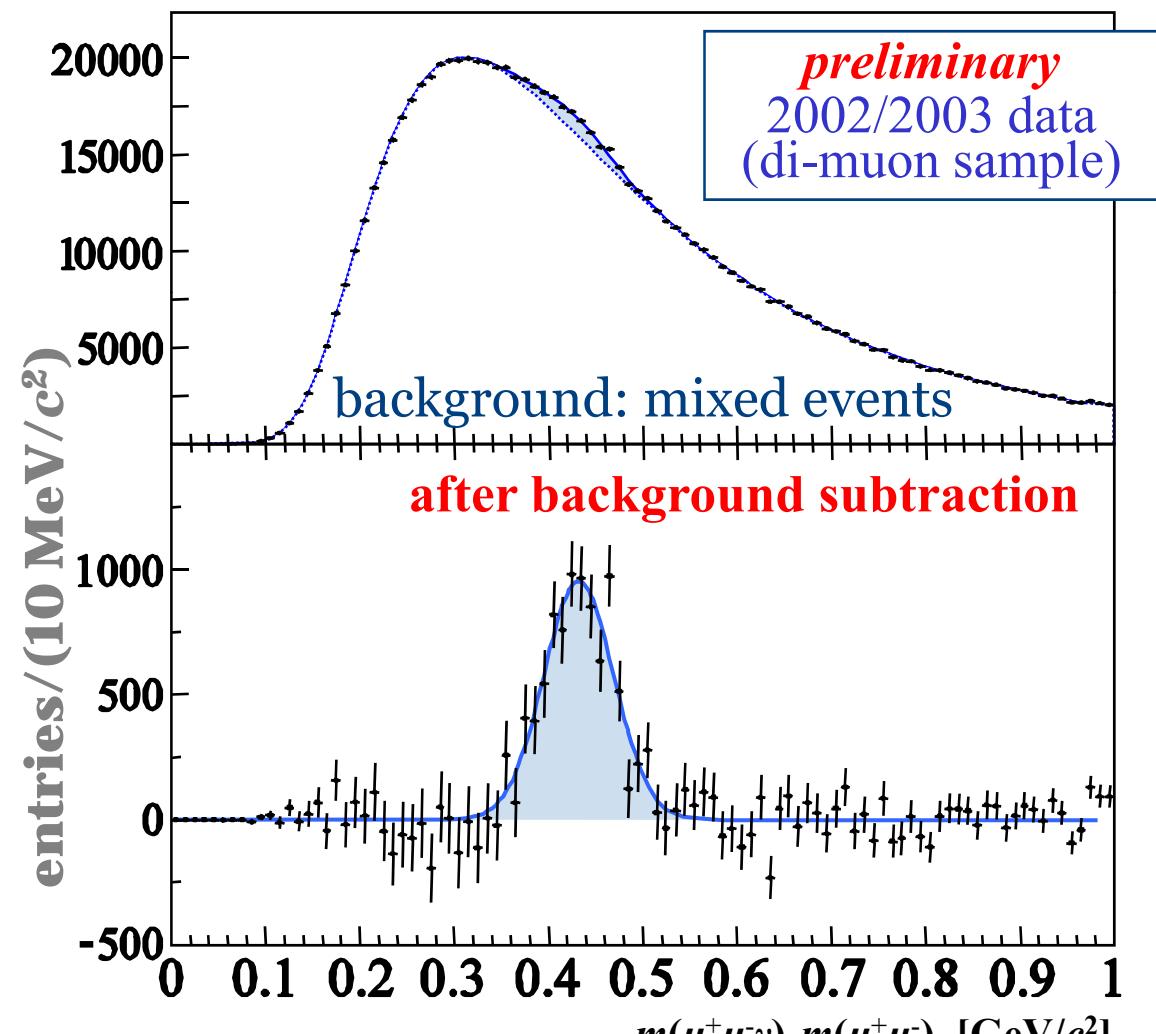
- kinematical distributions

2000 data sample:

370 ± 74 χ_c 's ($\mu^+\mu^- + e^+e^-$):

$$R(\chi_c) = 0.32 \pm 0.06 \pm 0.04$$

[Phys. Lett. B 561, 61 (2003)]

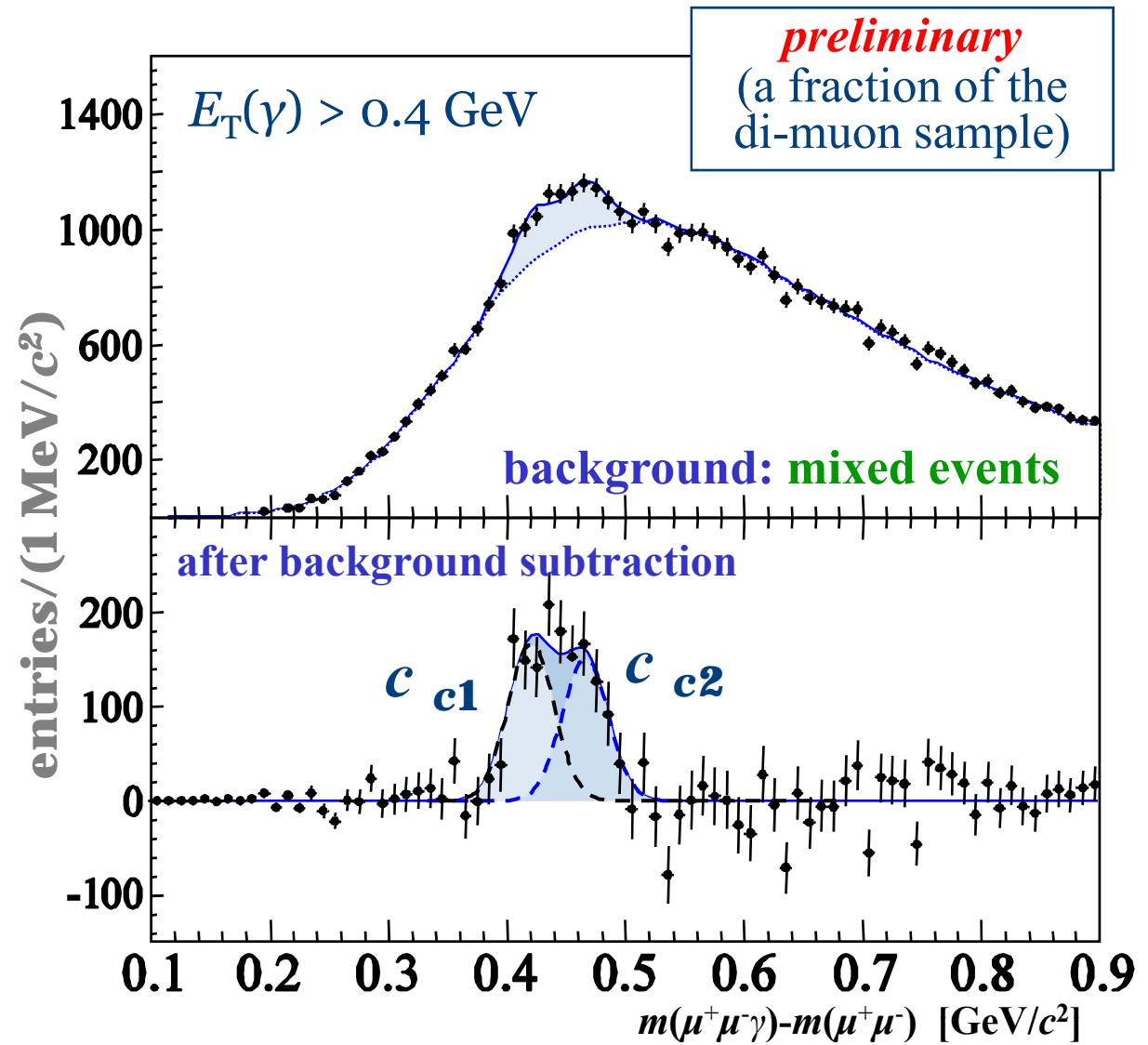


2002/03 data: 40× bigger χ_c statistics

$\chi_{c1} - \chi_{c2}$ Separation

further step:
separate different
states by varying
the selection cuts

measure the
 χ_{c2}/χ_{c1}
production ratio

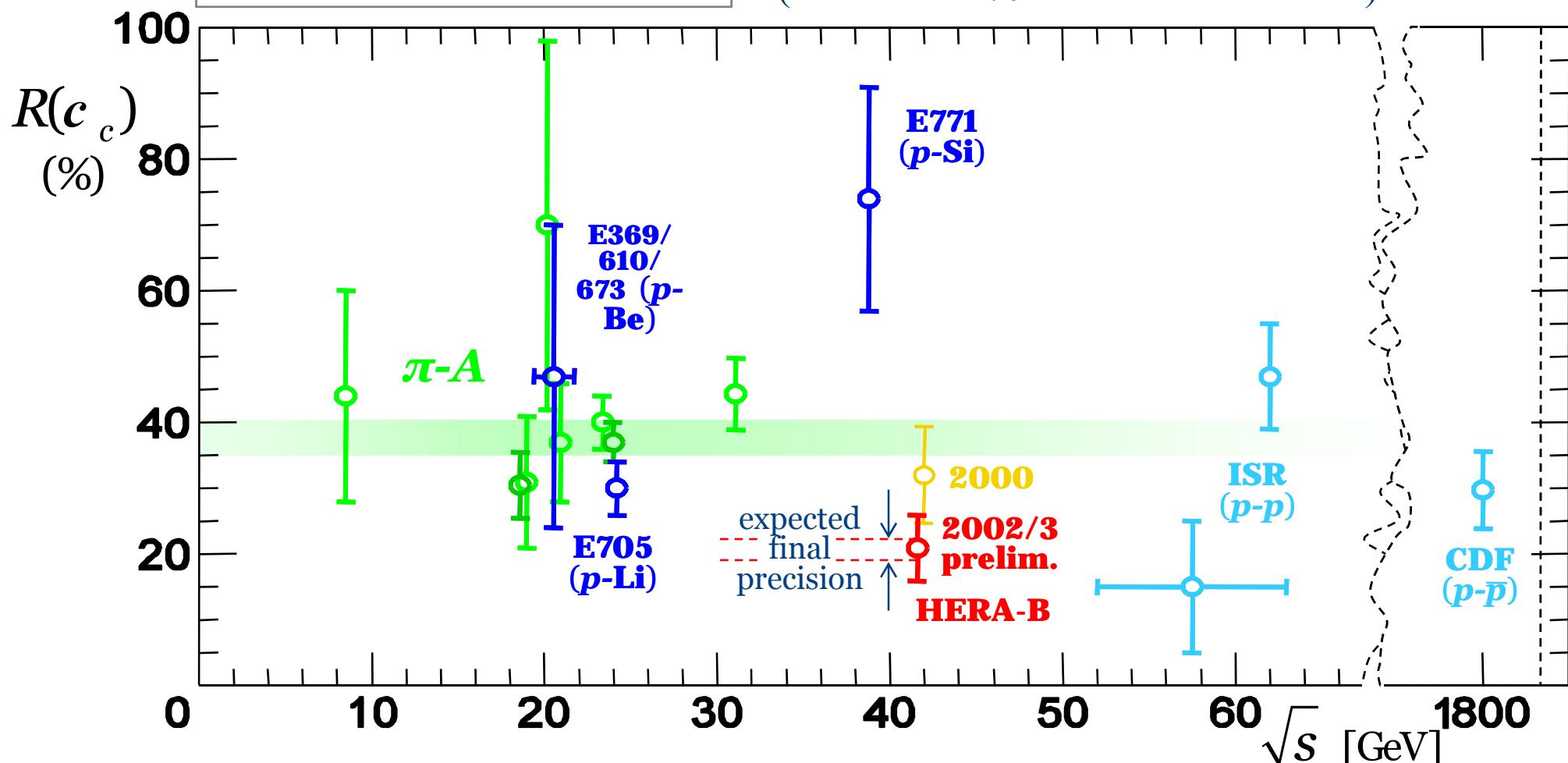


Production Cross Section Ratio $R(\chi_c)$

preliminary evaluation (2002/2003 data):

(21 ± 5)% of the produced
J/ ψ 's come from χ_c decays

based on 1300 χ_c 's
reconstructed in the di-muon channel
(less than 10% of the total statistics)



HERA-B collected 300000 J/ψ and 220 Mio min.bias events on different nuclei

Results on charmonium production (partly preliminary):

- J/ψ cross section
- J/ψ : x_F and p_T distributions in a new negative x_F range
 $J/\psi A$ dependence demonstrate a flat behavior in this region
- Fraction of χ_c and $\psi(2S)$ yields relative to J/ψ

Final results on J/ψ production, A-dependence, χ_c and $\psi(2S)$ are/will be published during 2006/2007

Backup - Slides

- HERA-B Di-Lepton Trigger
- A-dependence preliminary result

The Dilepton Trigger

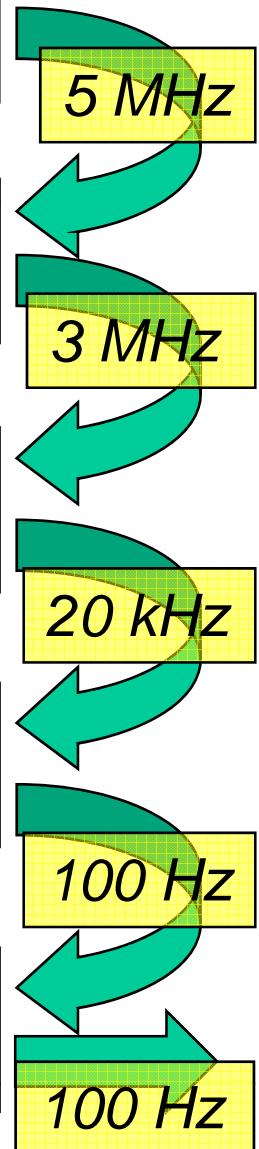
HERA-B detector: data is read out and buffered for 12 μ s
(proton bunches cross every 96 ns, 0.5 interactions/BX)

PreTriggers: ECAL cluster or muon hit coincidence as trigger seed (custom hardware)

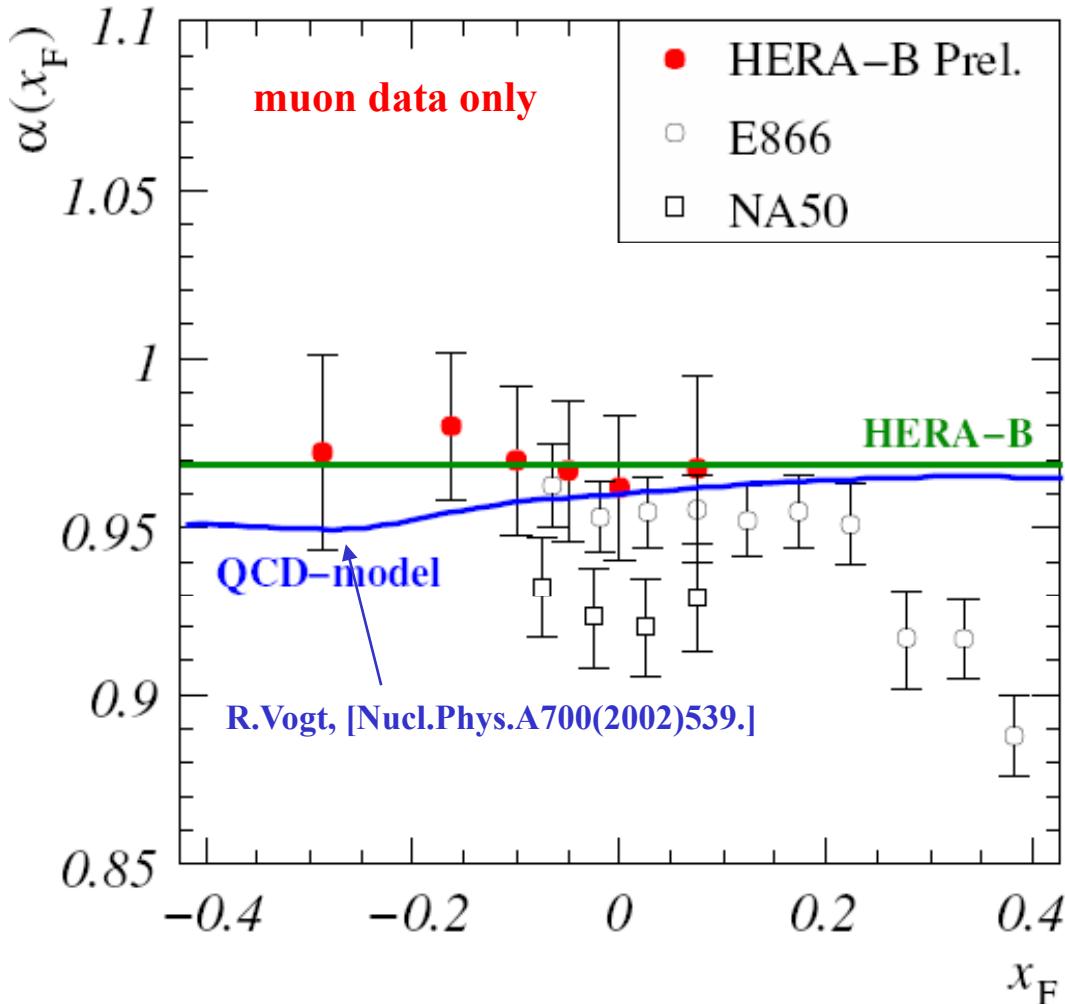
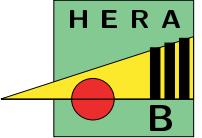
First Level Trigger (FLT): Track trigger in hardware using tracking detectors, seeding by pretriggers

Second Level Trigger (SLT): FLT tracking confirmed, extrapolation to vertex detector, 2 track vertex fit (PC farm)

Fourth Level Trigger (4LT): online reconstruction (and filtering) on PC farm, ca. 1500 rec. J/ ψ per h



J/ ψ : Nuclear Dependence



data sample of 2 – wire runs with different materials (**carbon/tungsten**)

first measurement at $x_F < -0.1$:
constant small suppression

$$\alpha = 0.969 \pm 0.003_{\text{stat}} \pm 0.021_{\text{sys}}$$