Recent Charmonium Results from HERA-B

XV International Workshop on

Deep-Inelastic Scattering 2007

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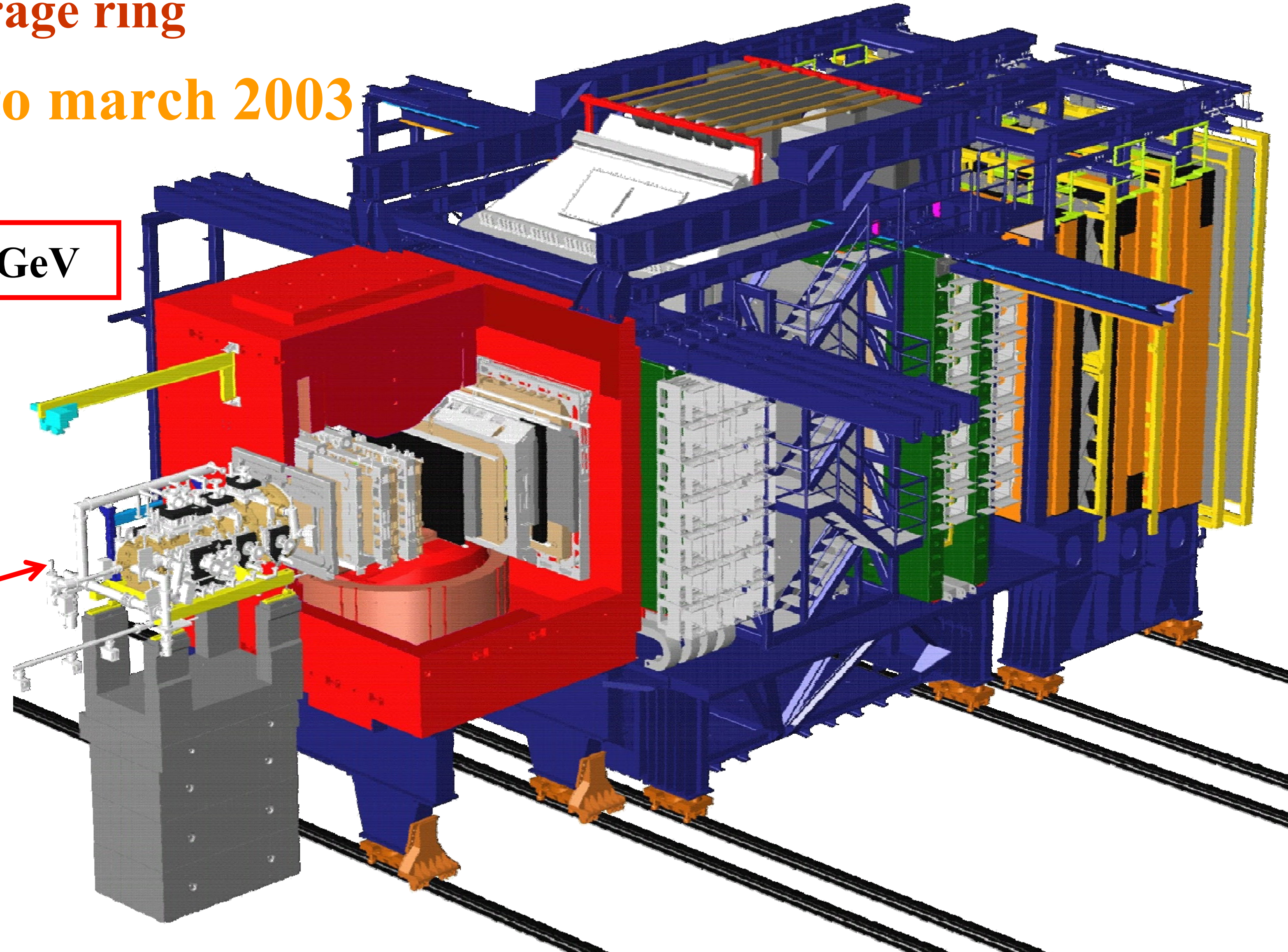
for the *HERA-B Kollaboration*

The HERA-B Experiment

at the HERA storage ring

data taking up to march 2003

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



920 GeV protons

Contents

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

Part 1

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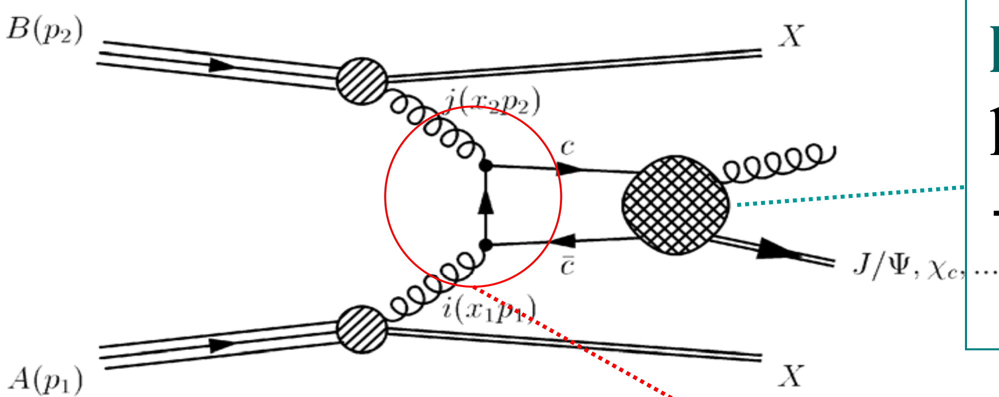
Proton-Nucleus Interaction

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

PDF



hadronization

long distance (~1/(m_cv)) process

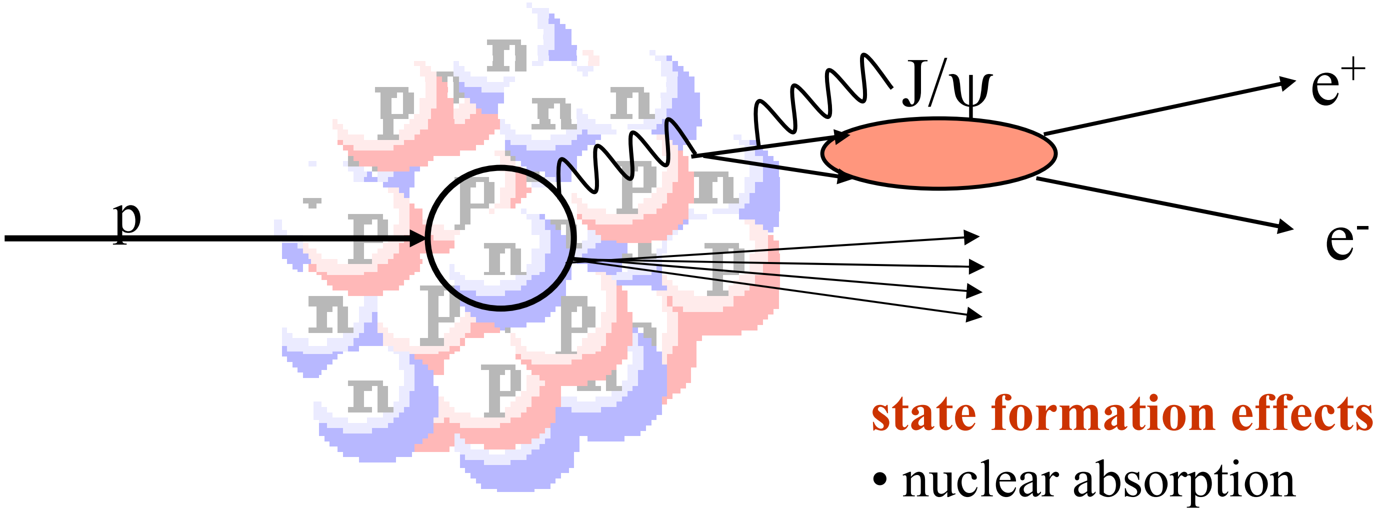
→non-perturbative calculations + input from experiments

$q\bar{q}$ formation

short distance (~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

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

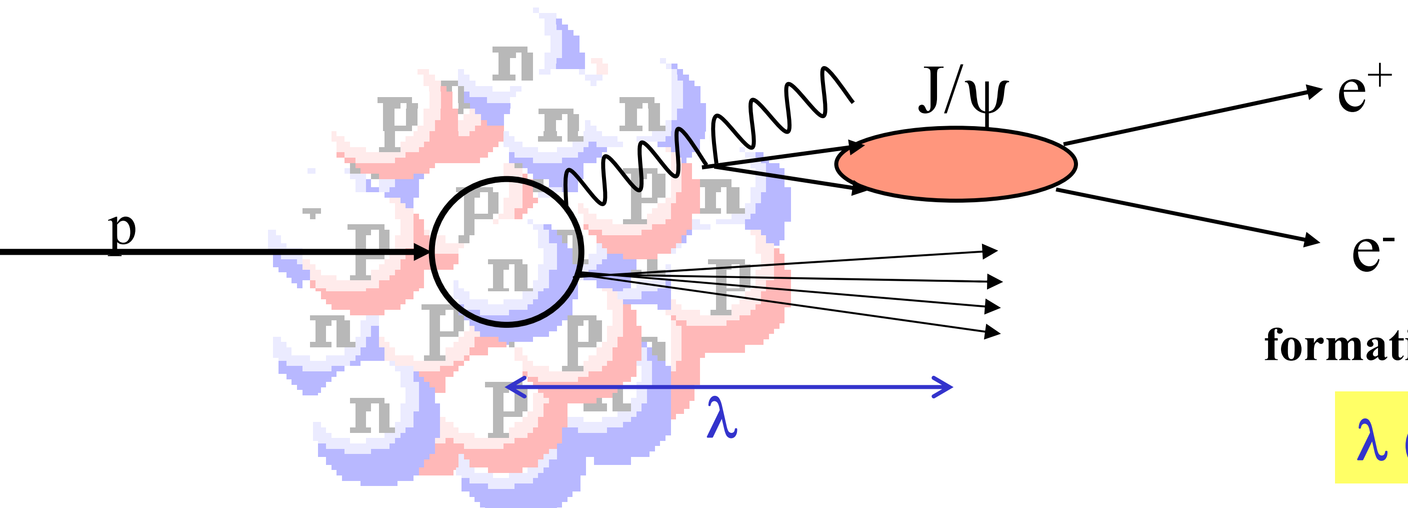
$\alpha \neq 1 \Rightarrow$ "suppression"

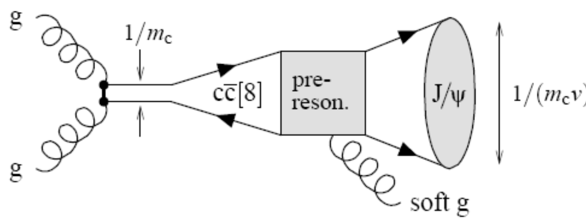
HERA-B:

measurement of α using 2 wire materials:

$$\alpha = \frac{\log\left(\frac{\sigma_2}{\sigma_1}\right)}{\log\left(\frac{A_2}{A_1}\right)} = \frac{\log\left(\frac{N_2}{N_1}\frac{L_1}{L_2}\frac{\varepsilon_1}{\varepsilon_2}\right)}{\log\left(\frac{A_2}{A_1}\right)}$$

x_F-Dependence of Nuclear Suppression

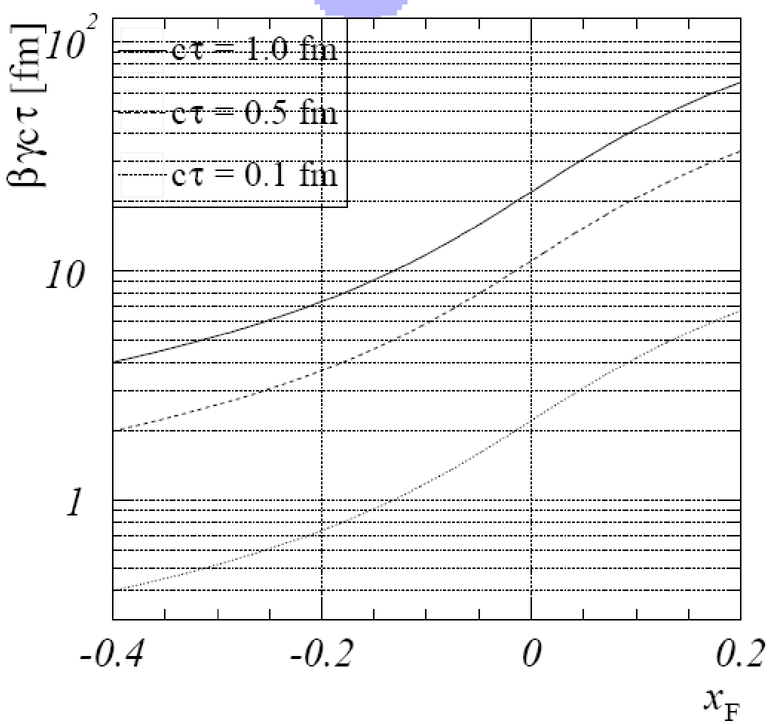




formation time and length:

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

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



for cτ = 0.5 fm	
x_F	λ [fm]
0.2	30
0	10
-0.2	4

Nuclear radius:
C ~ 3 fm.
W ~ 8 fm.

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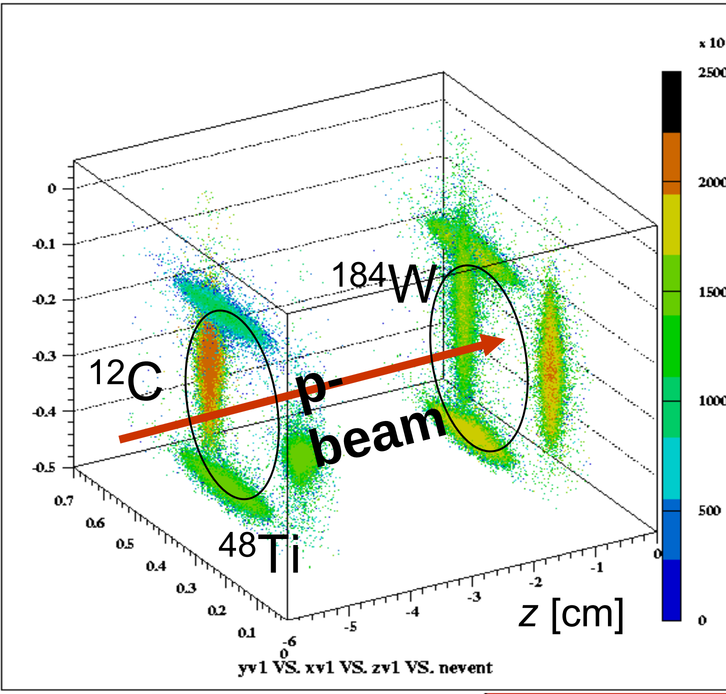
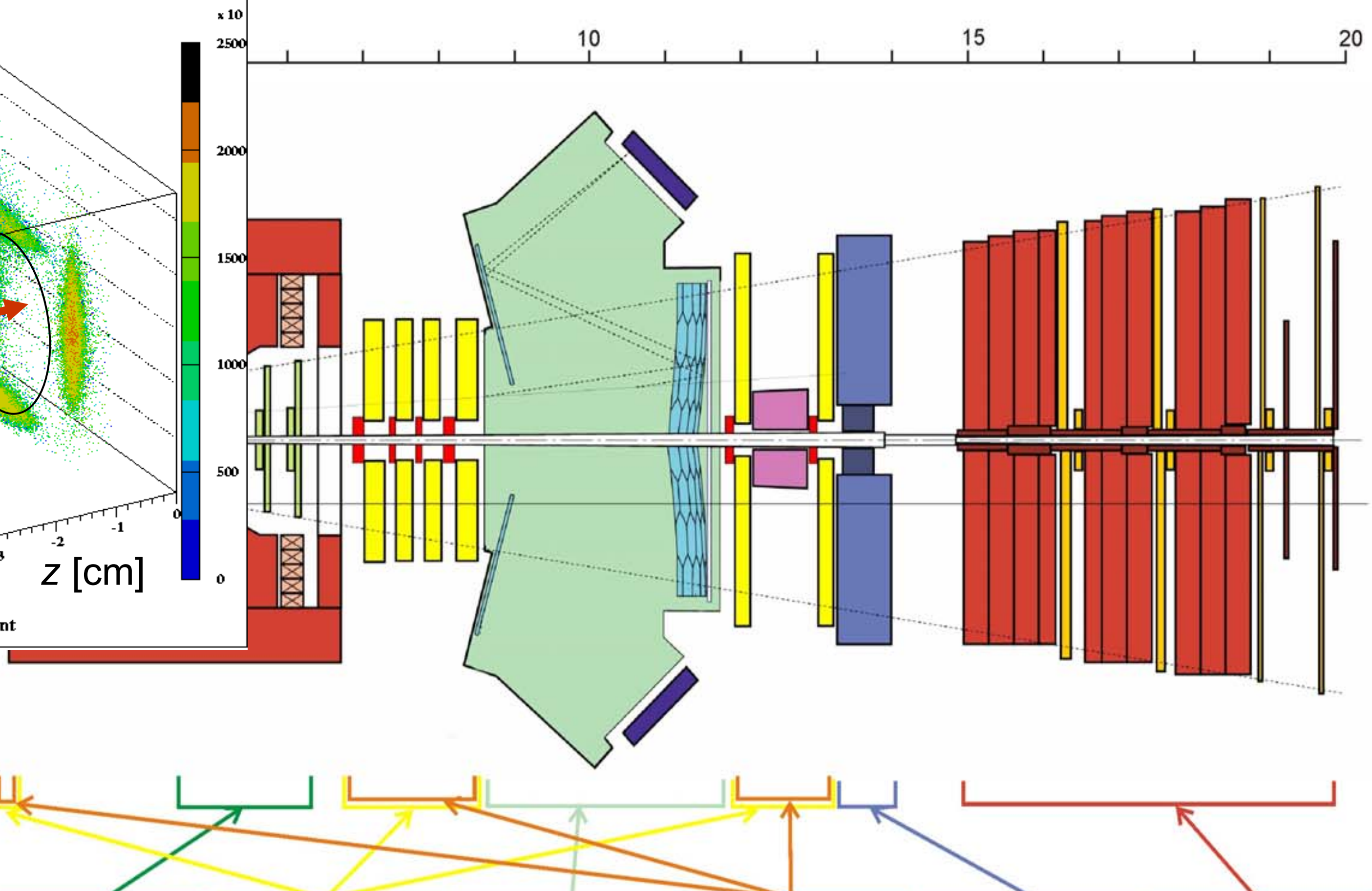
The HERA-B Detector





Target & Vertex
8 layers of double-sided Si-microstrips, movable on Roman-Pots; 8 wire-target (see above)

High p_T
3 superlayers gas, pixel and pad chambers; pre-trigger for high p_T tracks

Outer Tracker
7 superlayers of honeycomb drift chambers, 5 and 10mm cells

RICH
Spherical mirror inside C_4F_{10} radiator, Lens-enhanced multianode PMT focal plane.

Inner Tracker
7 superlayers of Micro Strip Gas Chambers with GEM-foil

Electromagnetic Calorimeter
W/Pb scintillator sandwich, shashlik WLS readout with PMTs; energy-cluster pre-trigger

Muon System
4 superlayers of gas-pixel, tube & pad chambers; pad-coincidence pre-trigger

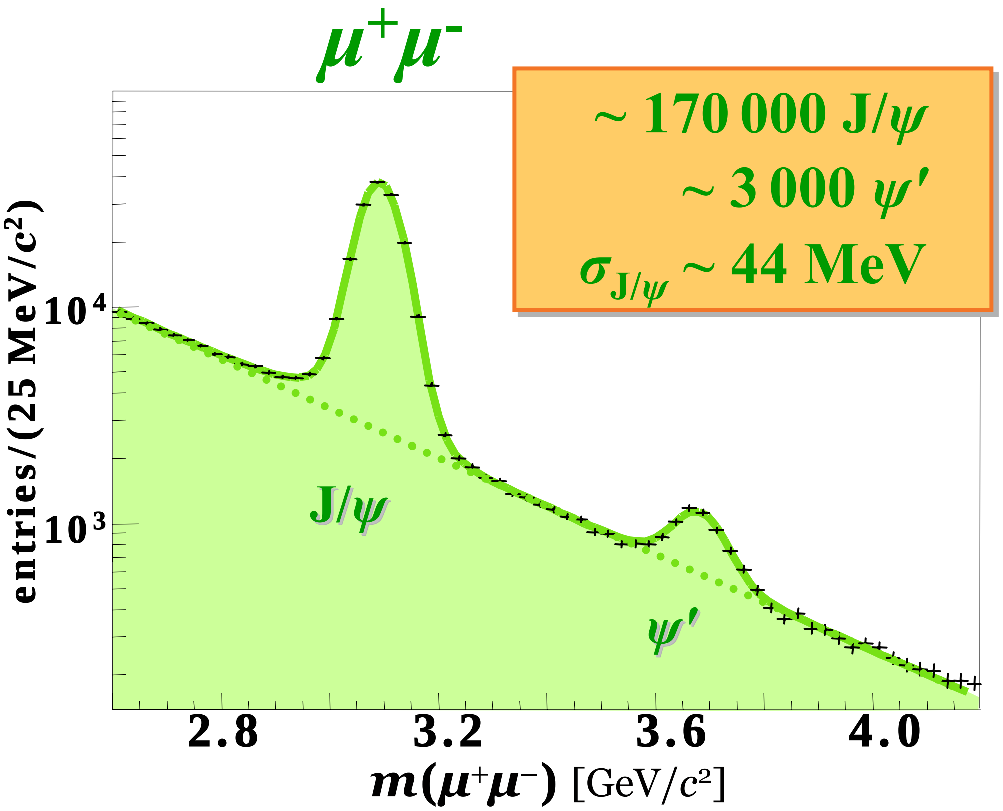
Main Data Samples

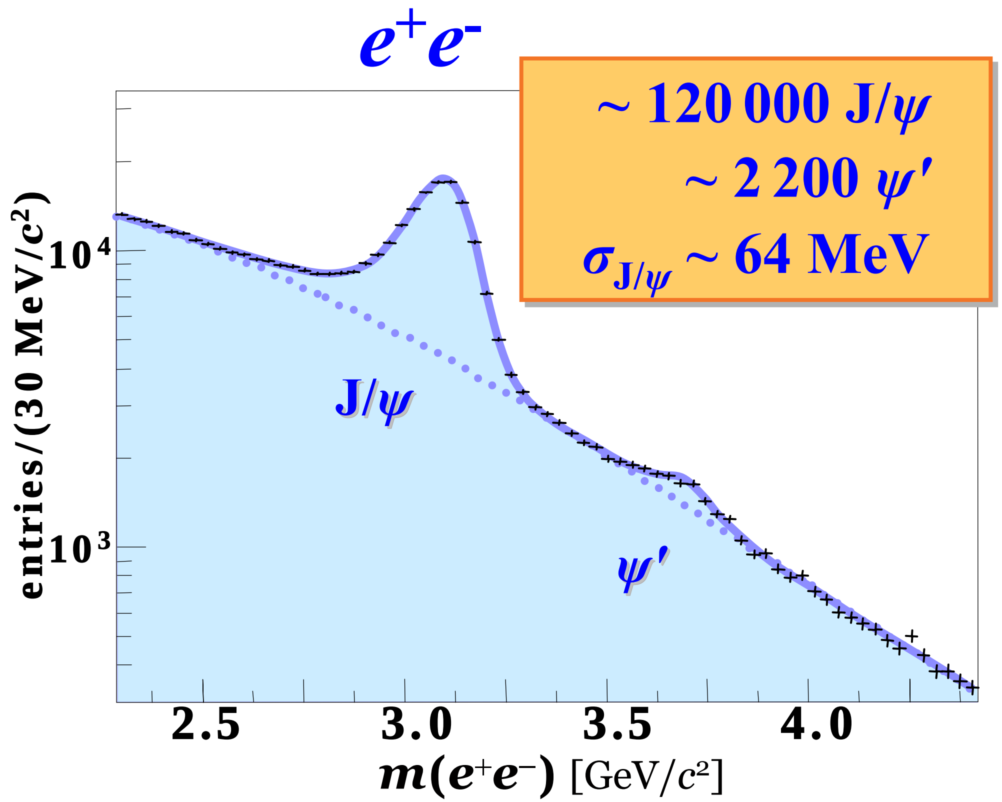
- **150 M di-lepton trigger events** (e^+e^- / $\mu^+\mu^-$ triggers)
  - ~ 300 000 J/ψ (>1000 per hour)
  - ~ 15 000 χ_{c1}+ χ_{c2}
  - ~ 5 000 ψ(2S)
- **210 M minimum bias events**

→ 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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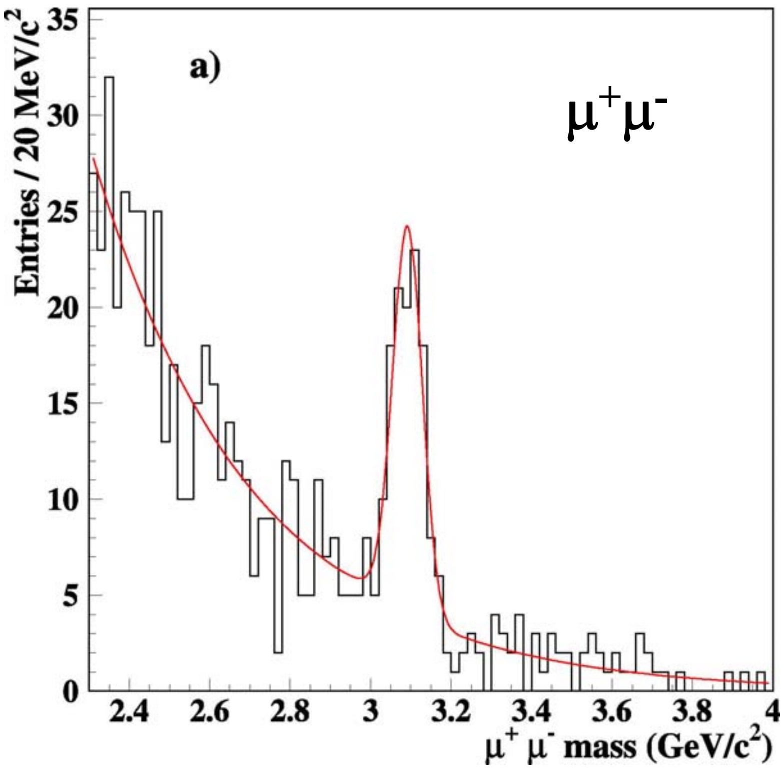
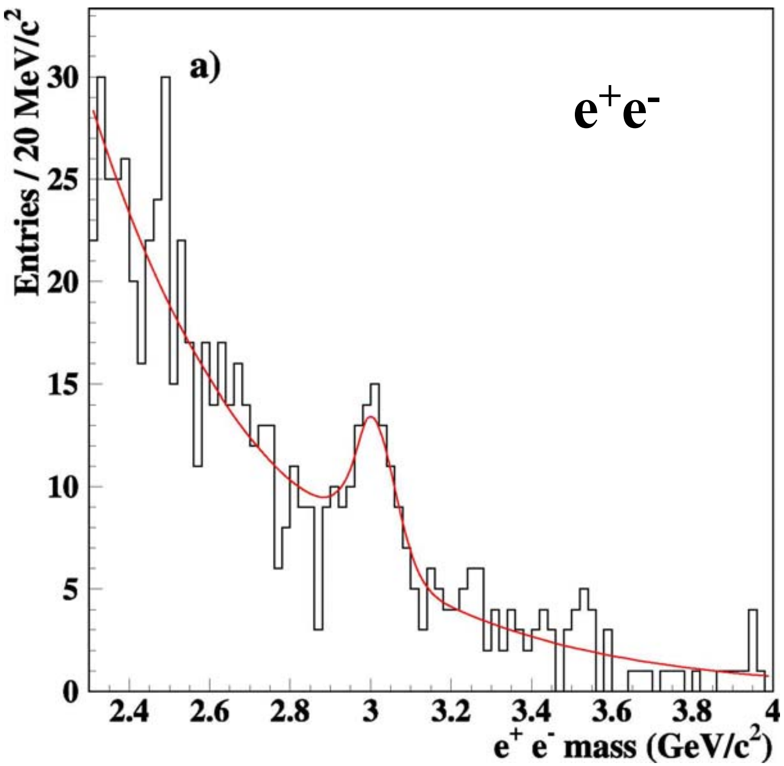
J/ψ Production Cross Section from Minimum Bias data

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

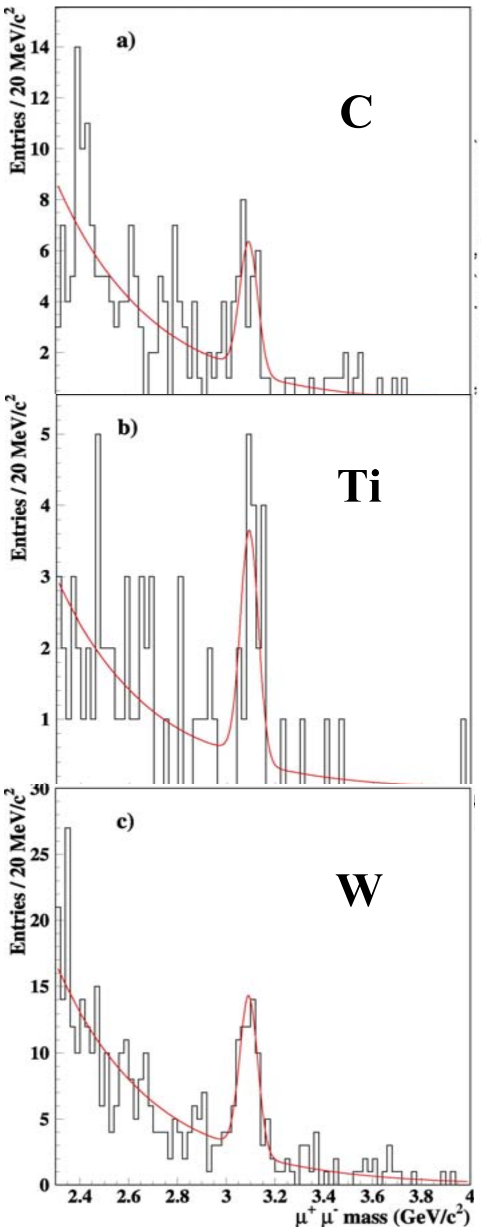


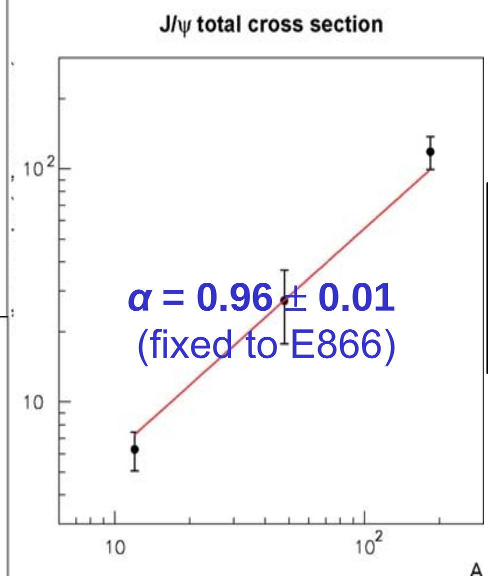


- **independent data sample**
- efficiency and luminosity well understood

⇒ systematic uncertainties small (usually dominant)

J/ψ (MinB): A-Dependence and Results





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

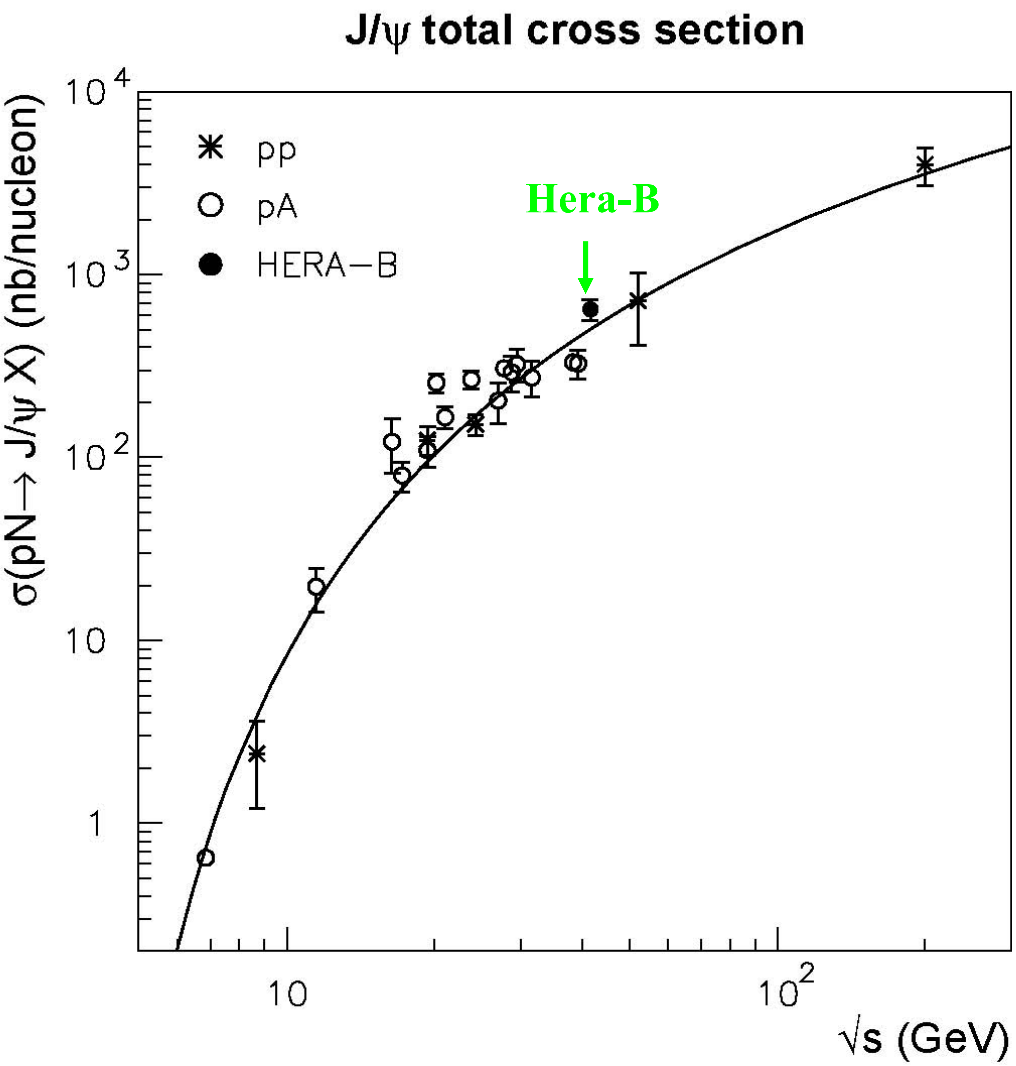
results:

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

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

[Phys.Lett.B638(2006)407]

J/ψ (MinB) : Combination with other Experiments



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:

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

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

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

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

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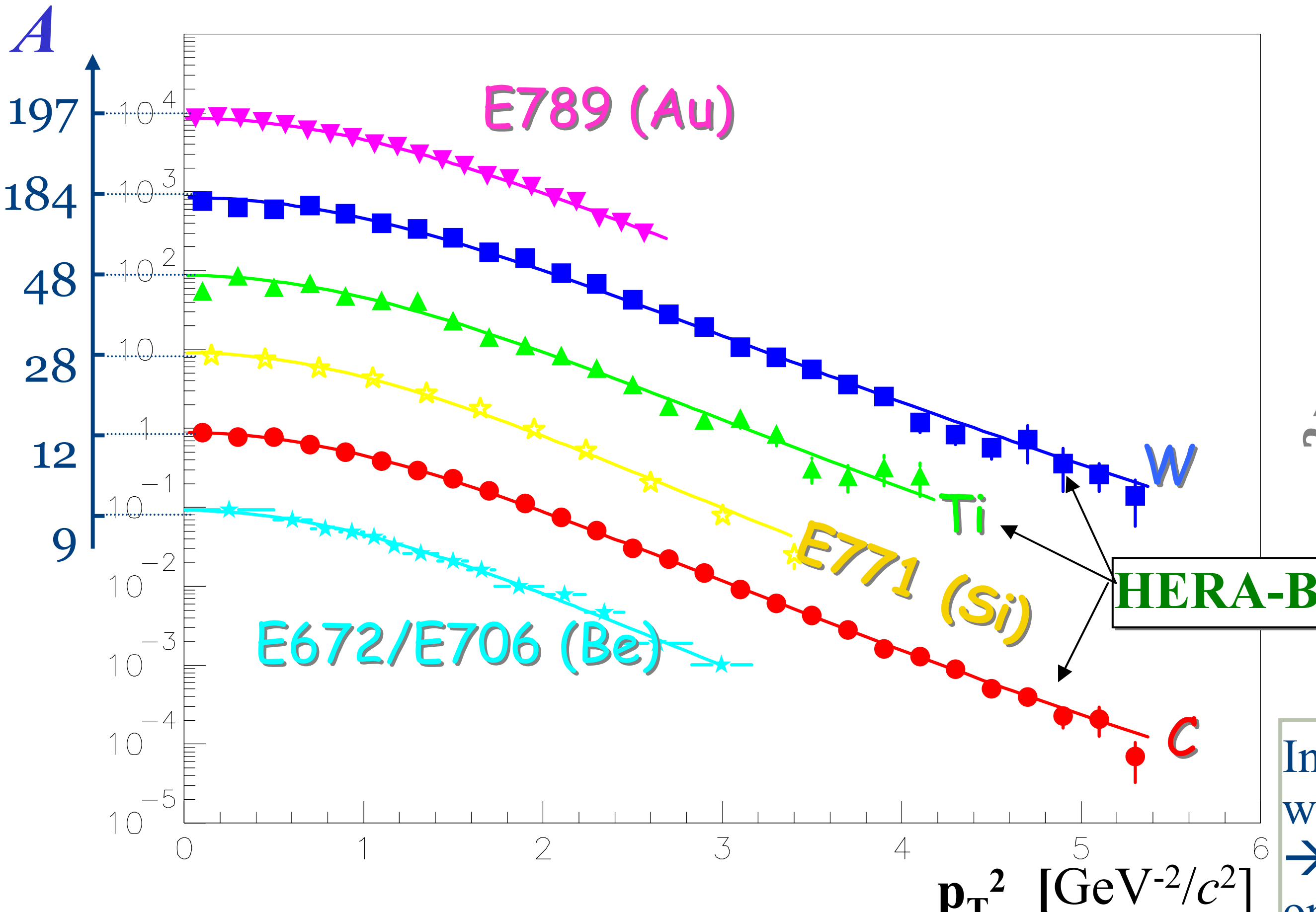
J/ψ p_T Distributions (Nuclear Dependence)

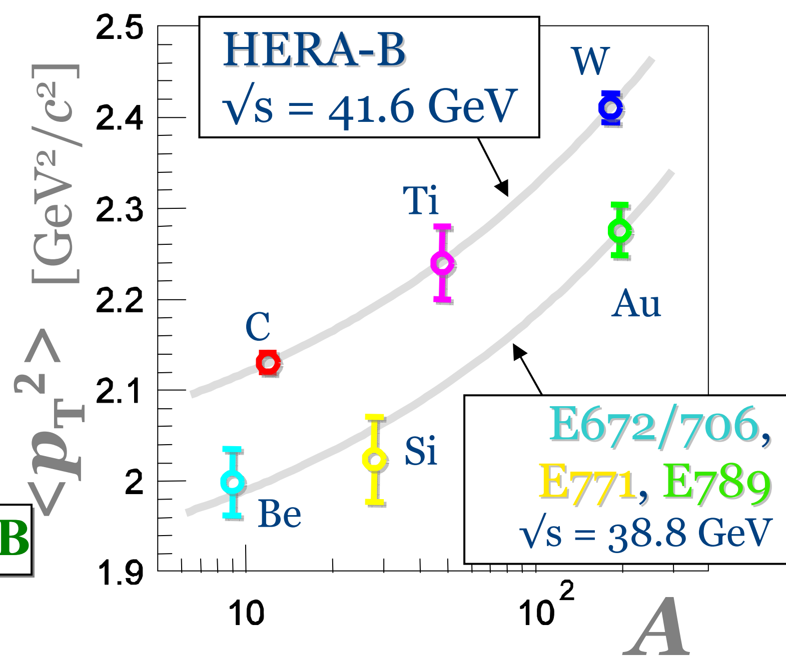
preliminary data (di-electron only), compared with *p-A* results at similar energy ($\sqrt{s}$ = 38.8 GeV)

standard fit:

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

→ Kinematic range enlarged

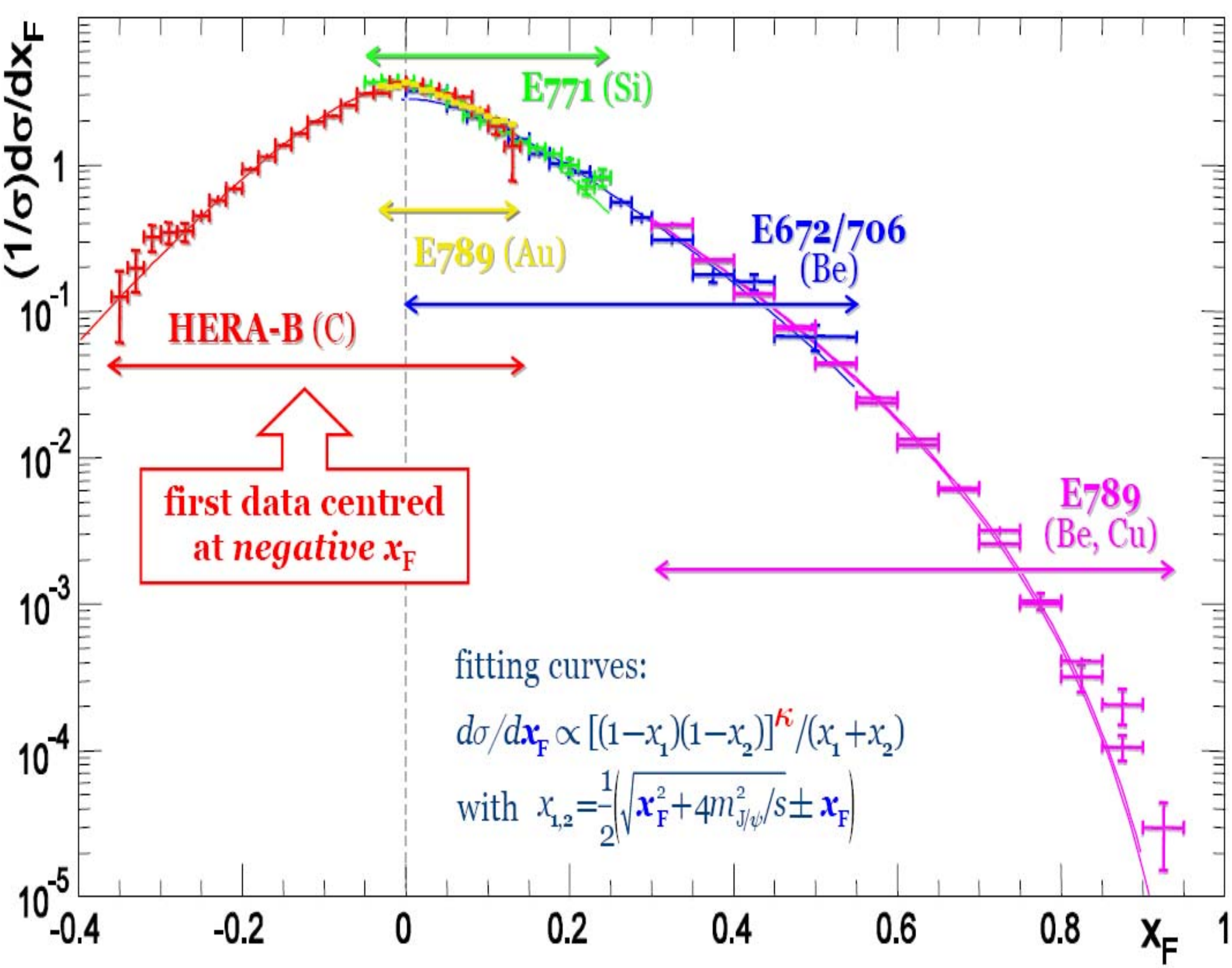




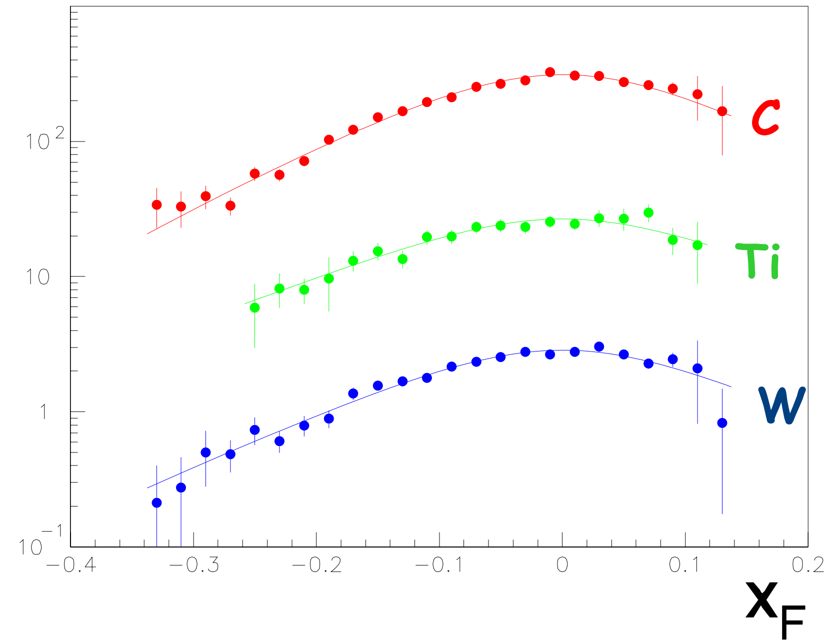
Increase of $\langle p_T^2\rangle$ with cms energy and with A.
→ Consistent with a linear dependence on the nuclear path length.

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 (√s=38.8 GeV) agreement with muon channel in all distributions.

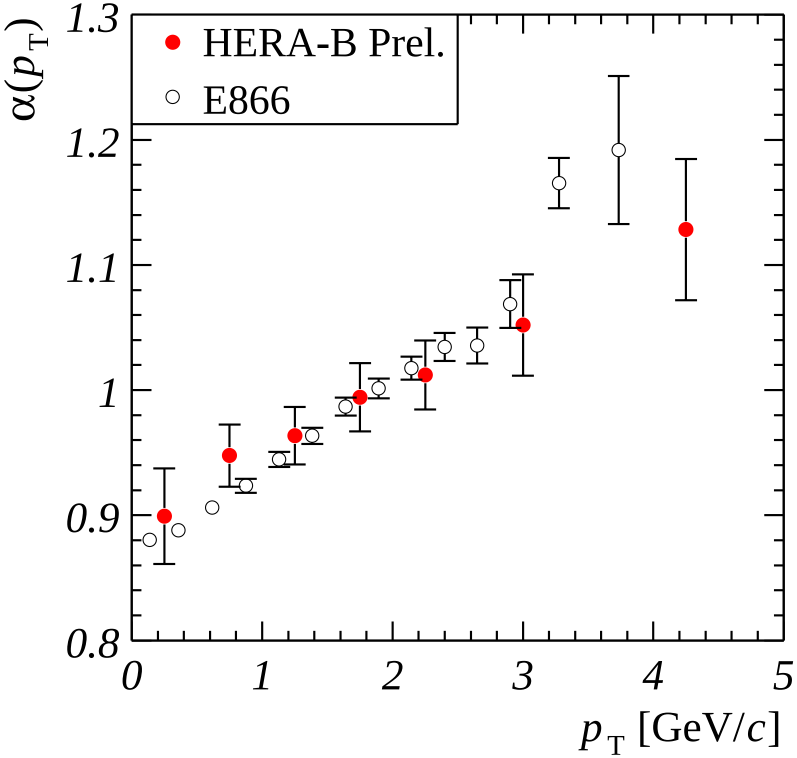
J/ψ *A*-Dependence

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

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

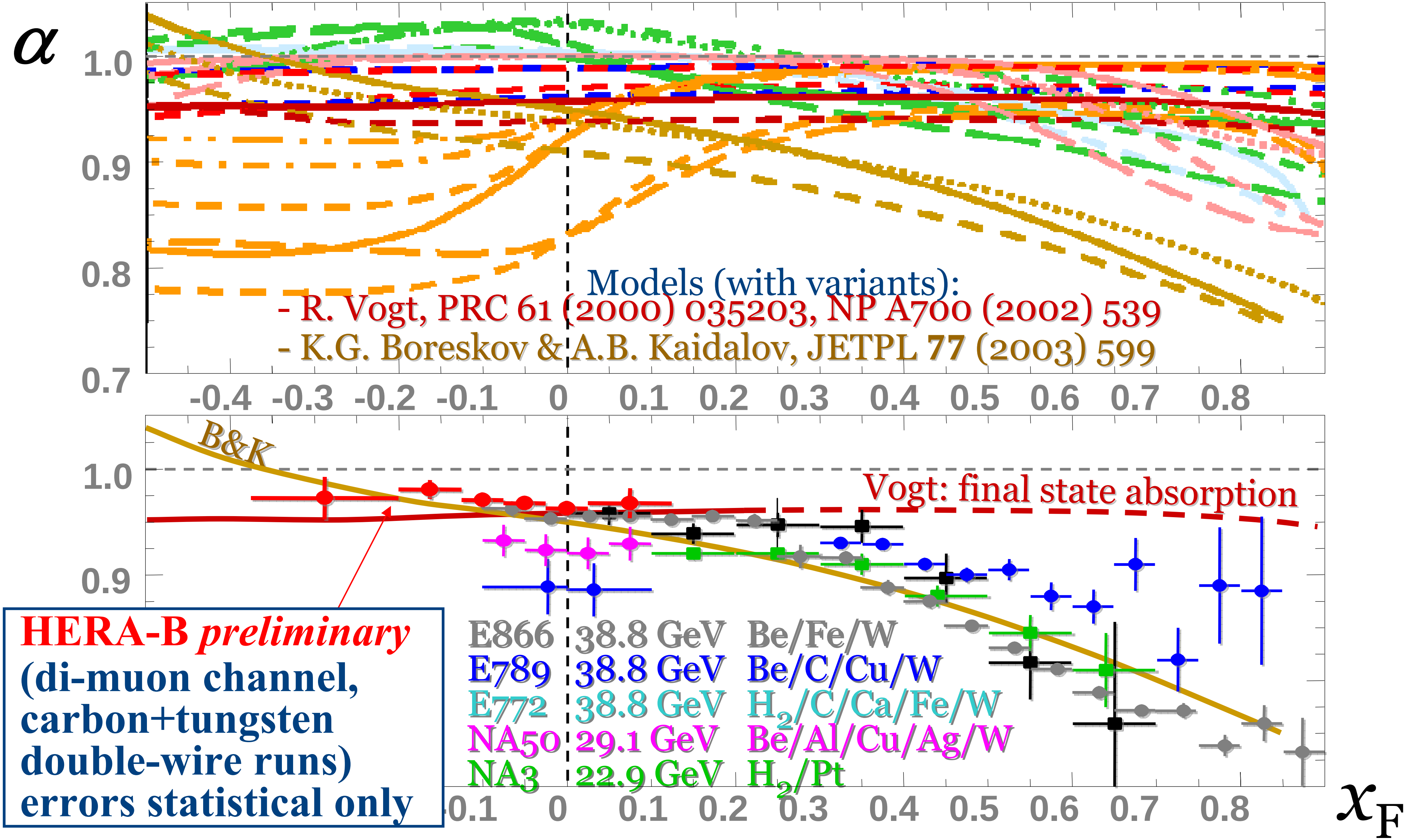
- **α < 1**: charmonium suppression by nuclear effects
- **HERA-B**: extract α from runs with two target wires simultaneously (carbon: *A*=12, tungsten: *A*=184)

- 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



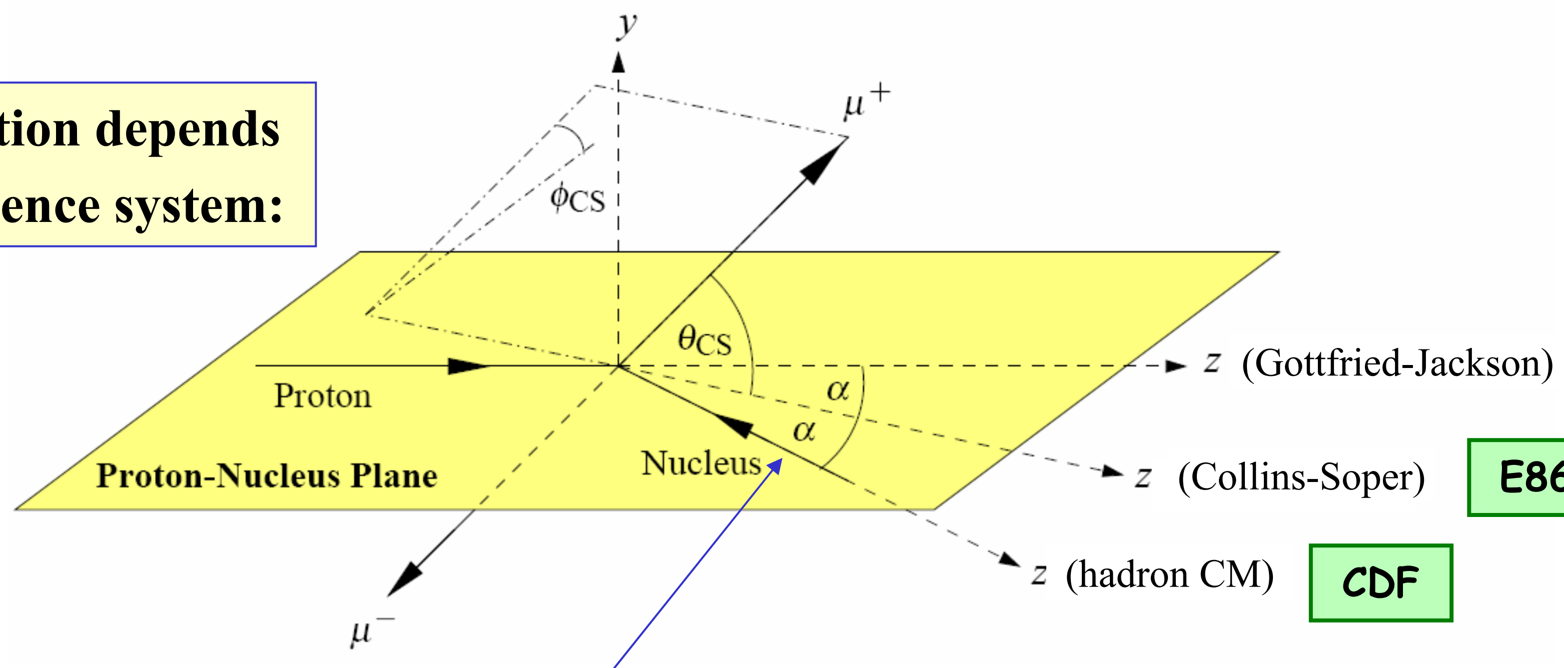
HERA-B *preliminary*
(di-muon channel, carbon+tungsten double-wire runs) errors statistical only

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:



E771, E672/E706 — z (Gottfried-Jackson)

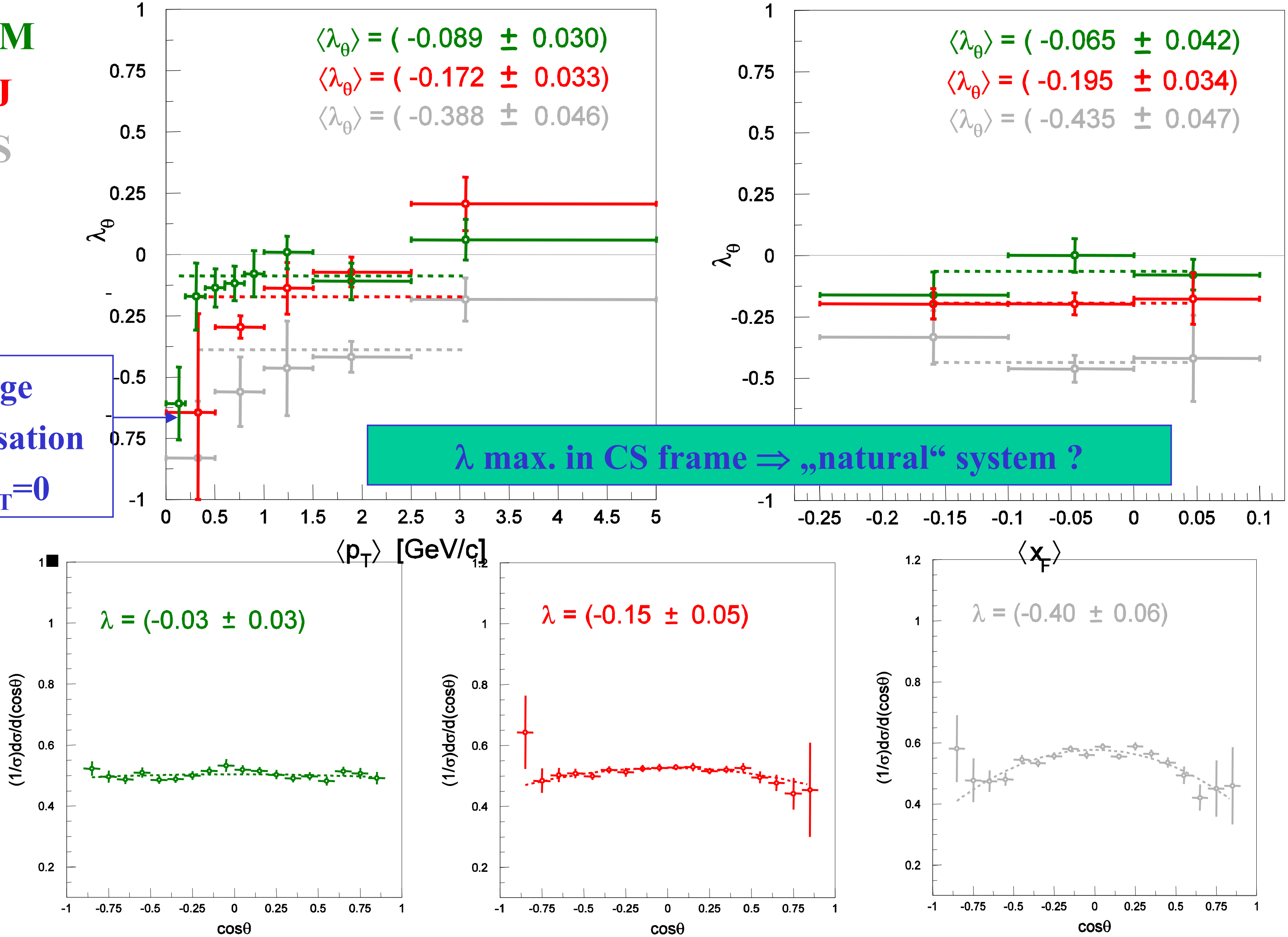
E866 — z (Collins-Soper)

CDF — z (hadron CM)

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

Preliminary Polarisation Results

HCM
GJ
CS



large polarisation at p_T=0

λ max. in CS frame ⇒ „natural“ system ?

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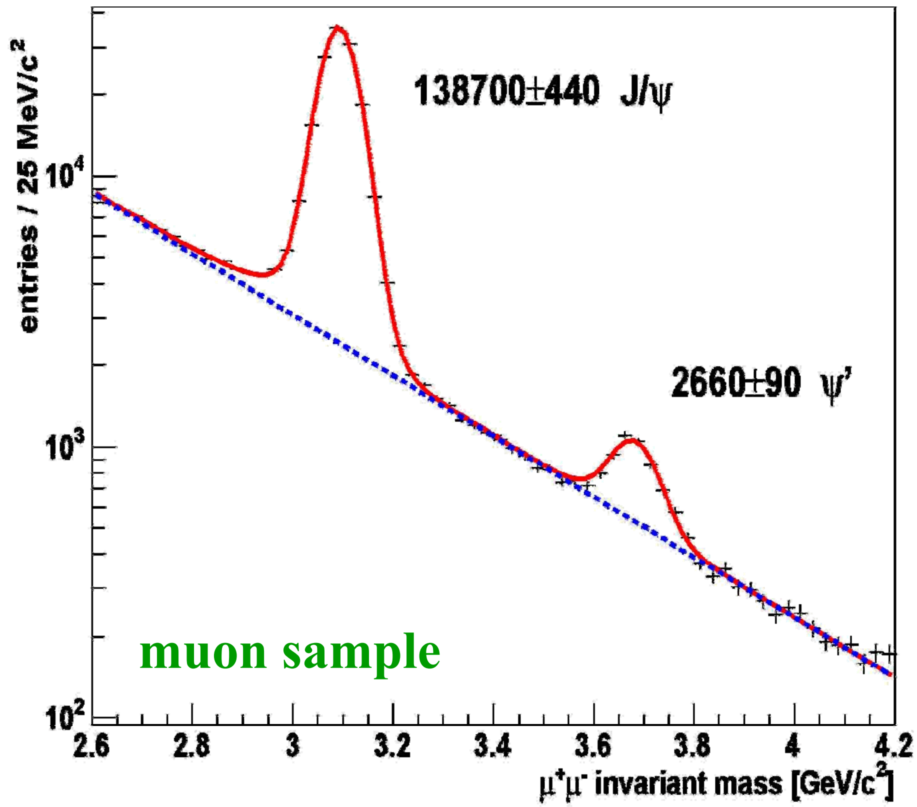
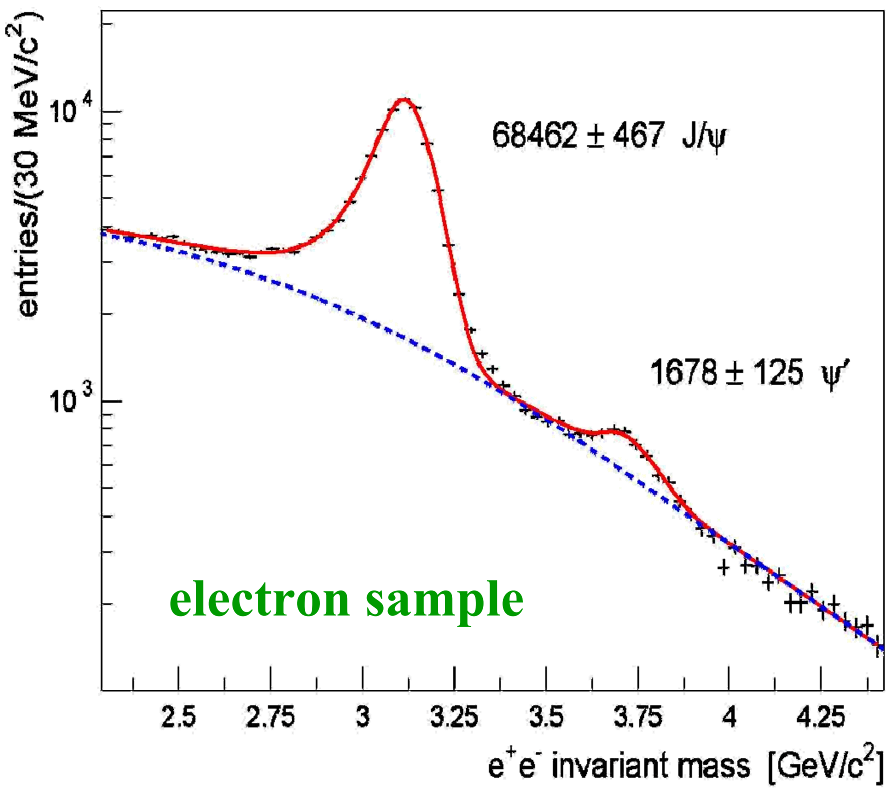
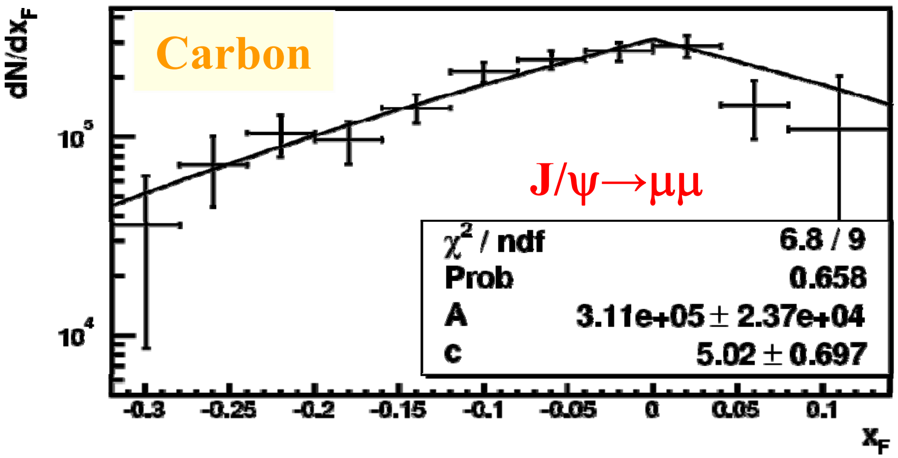
ψ'/ J/ψ Production Ratio

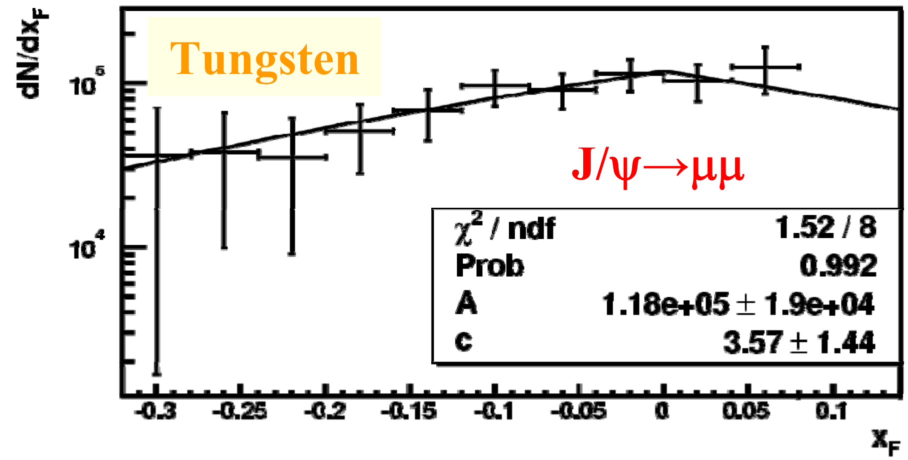


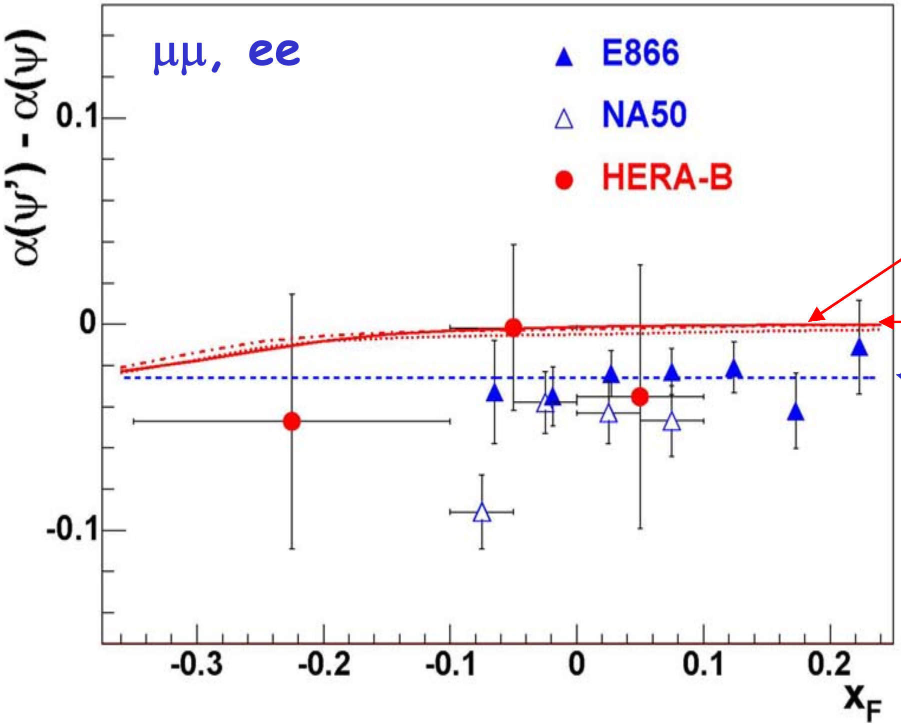


$$\frac{BR(\psi' \to l^+l^-)\cdot\sigma_{\psi'}}{BR(J/\psi \to l^+l^-)\cdot\sigma_{J/\psi}} = \frac{N_{\psi'}}{N_{J/\psi}}\frac{\varepsilon_{J/\psi}}{\varepsilon_{\psi'}}$$

Kinematical Distributions







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

CEM for color-1 nuclear absorption

NRQCD for color-1 & -8 nuclear absorption

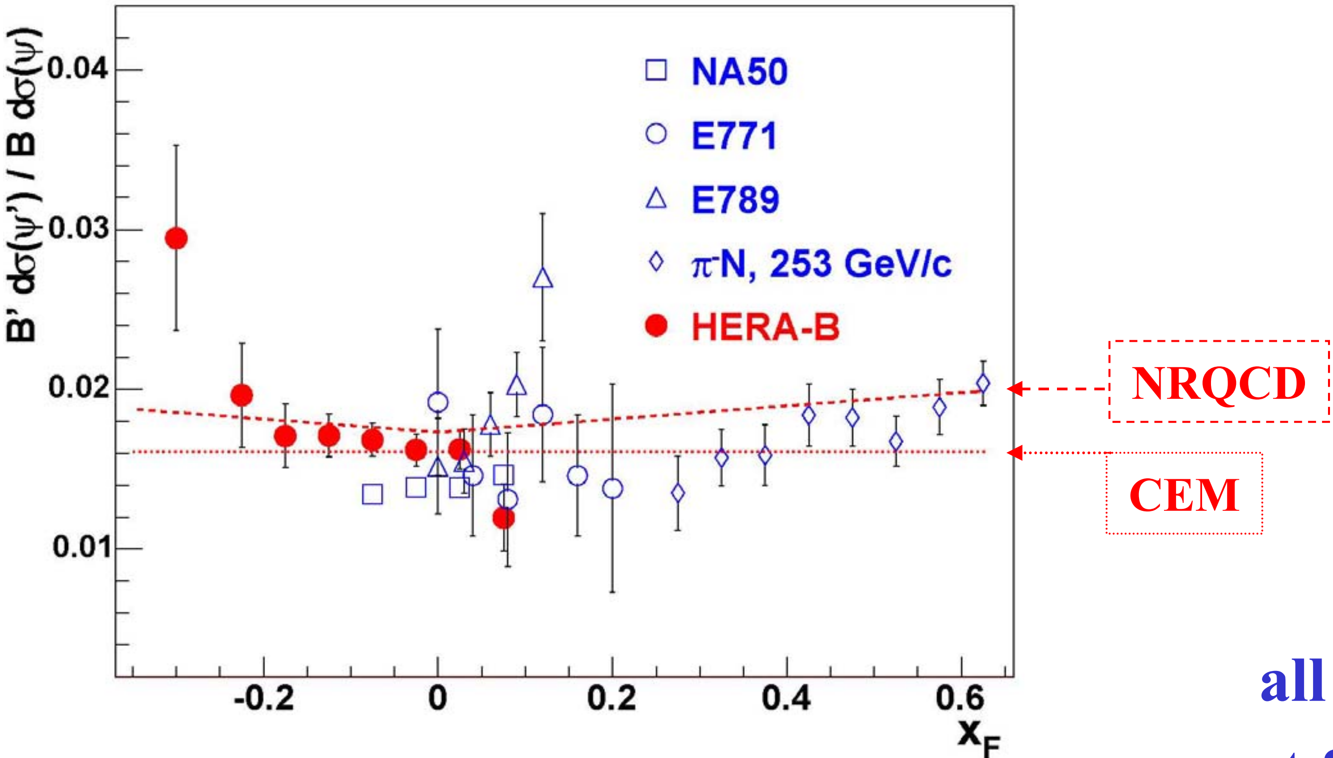
fit with const: $\Delta\alpha$(E866)=-0.026±0.005

all consistent with no x_F dependence.

average of E866 and NA50 is used:

$\Delta\alpha$(E866, NA50)=-0.030±0.004

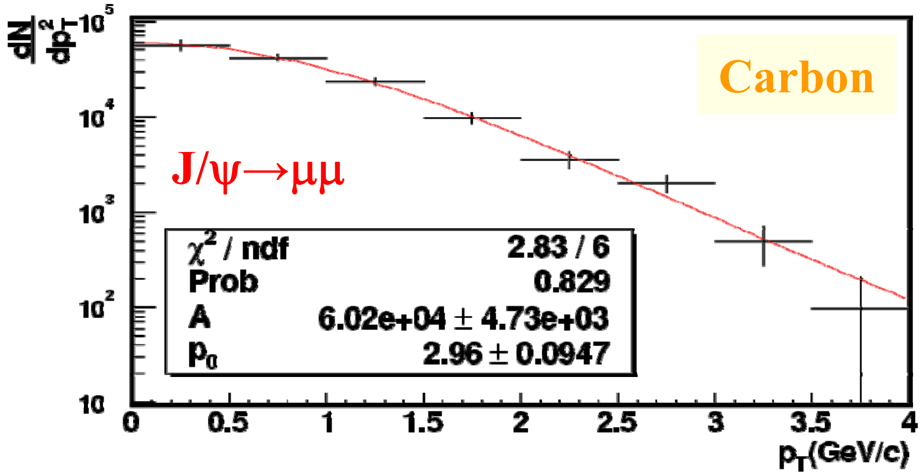
Feynman–x_F Dependence of ψ' Production Ratio

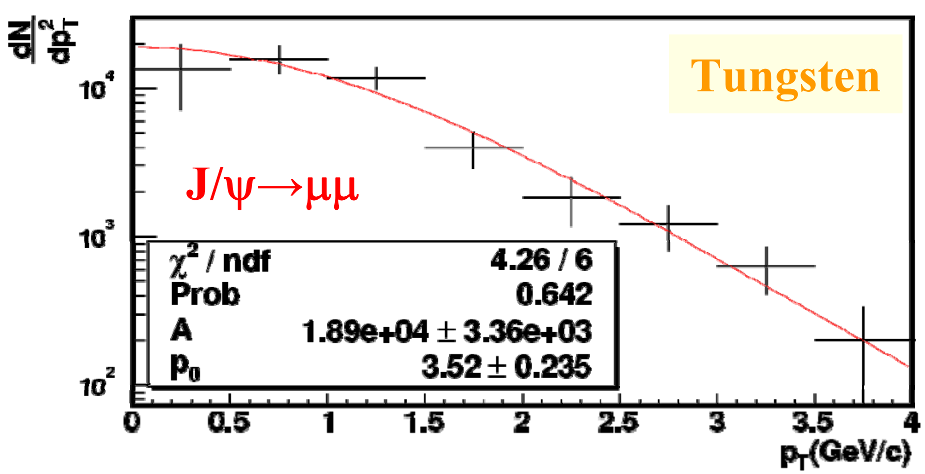


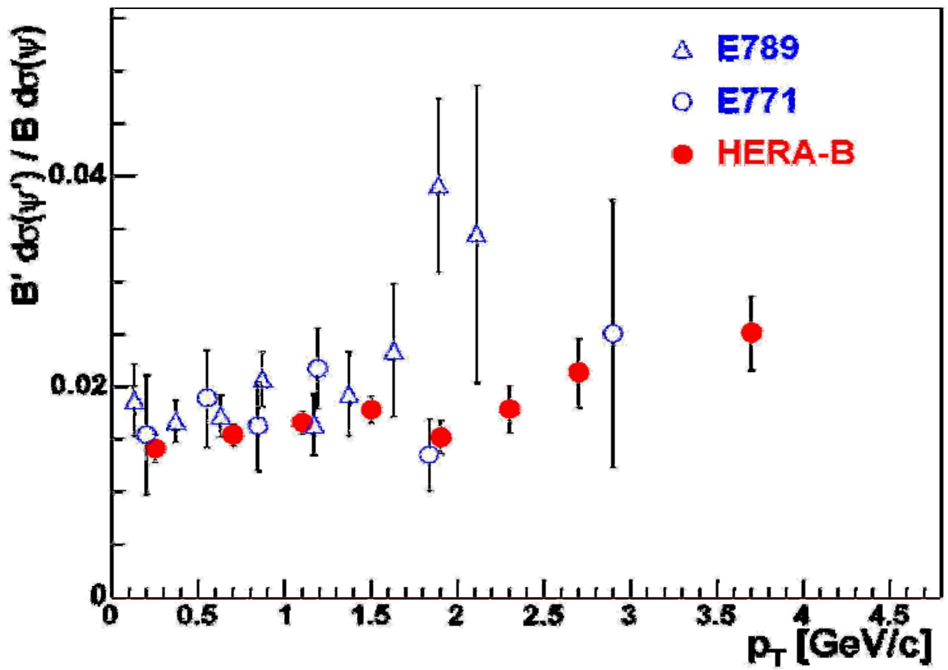
all targets included,
correct for nuclear effects with
Δα(E866, NA50)

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

ψ' production: p_T distributions

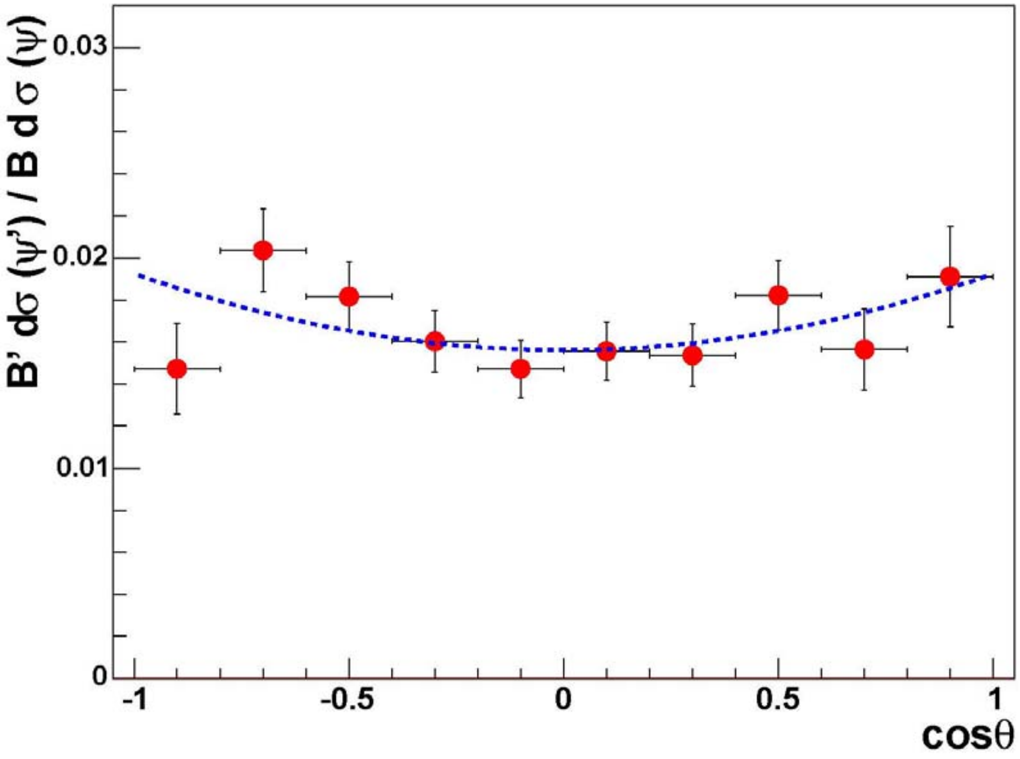






$\Rightarrow$ **tendency for a wider p_T distribution of ψ' (increasing with A?)**

Ψ' 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

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

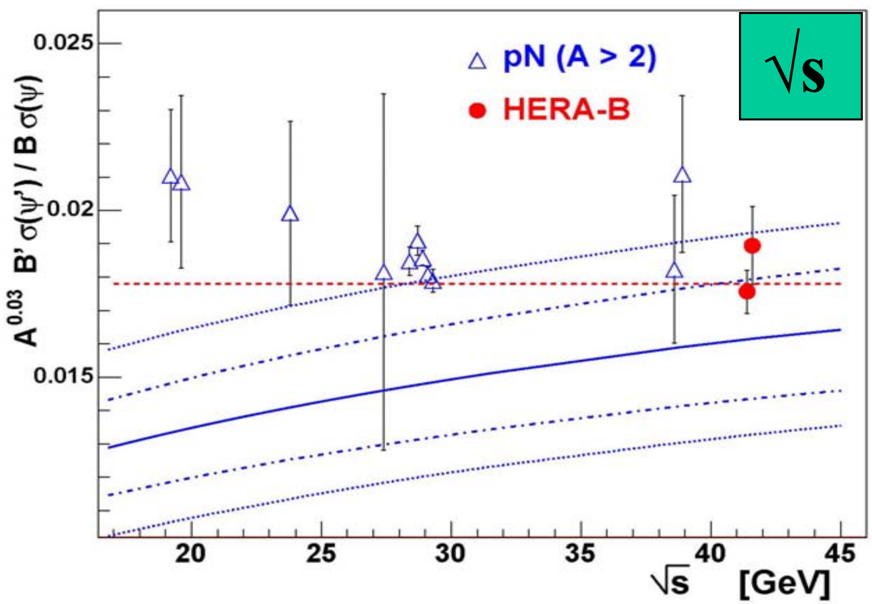
compatible with no polarisation difference

Production Ratio ψ' / J/ψ

$$B'\,\sigma'\,/\,B\,\sigma\ (\mathrm{C}) = 0.0163 \pm 0.0006 \pm 0.0004,$$
$$B'\,\sigma'\,/\,B\,\sigma\ (\mathrm{Ti}) = 0.0199 \pm 0.0024 \pm 0.0005,$$
$$B'\,\sigma'\,/\,B\,\sigma\ (\mathrm{W}) = 0.0162 \pm 0.0010 \pm 0.0004,$$

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

$$R_{1\psi'} = 0.0183 \pm 0.0003$$
$$\Delta\alpha = -0.029 \pm 0.004$$



in addition: μμ and ee measurements yield:

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

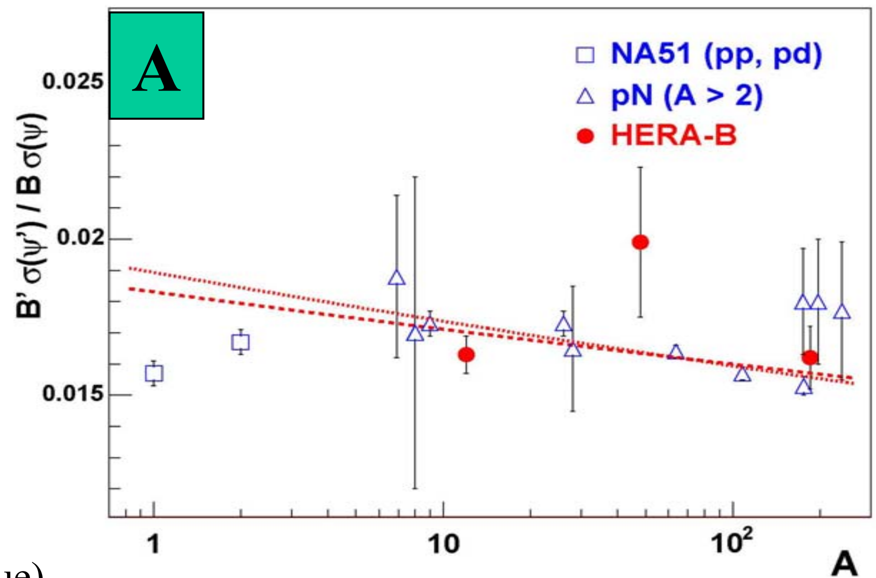
$$R_{\psi'}(\mu)/R_{\psi'}(e) = 1.00 \pm 0.08 \pm 0.04$$

current PDG avg.: 1.03 ± 0.12

⇒ **improvement of B'(μ):**

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

(better than current PDG value)



ψ' Production

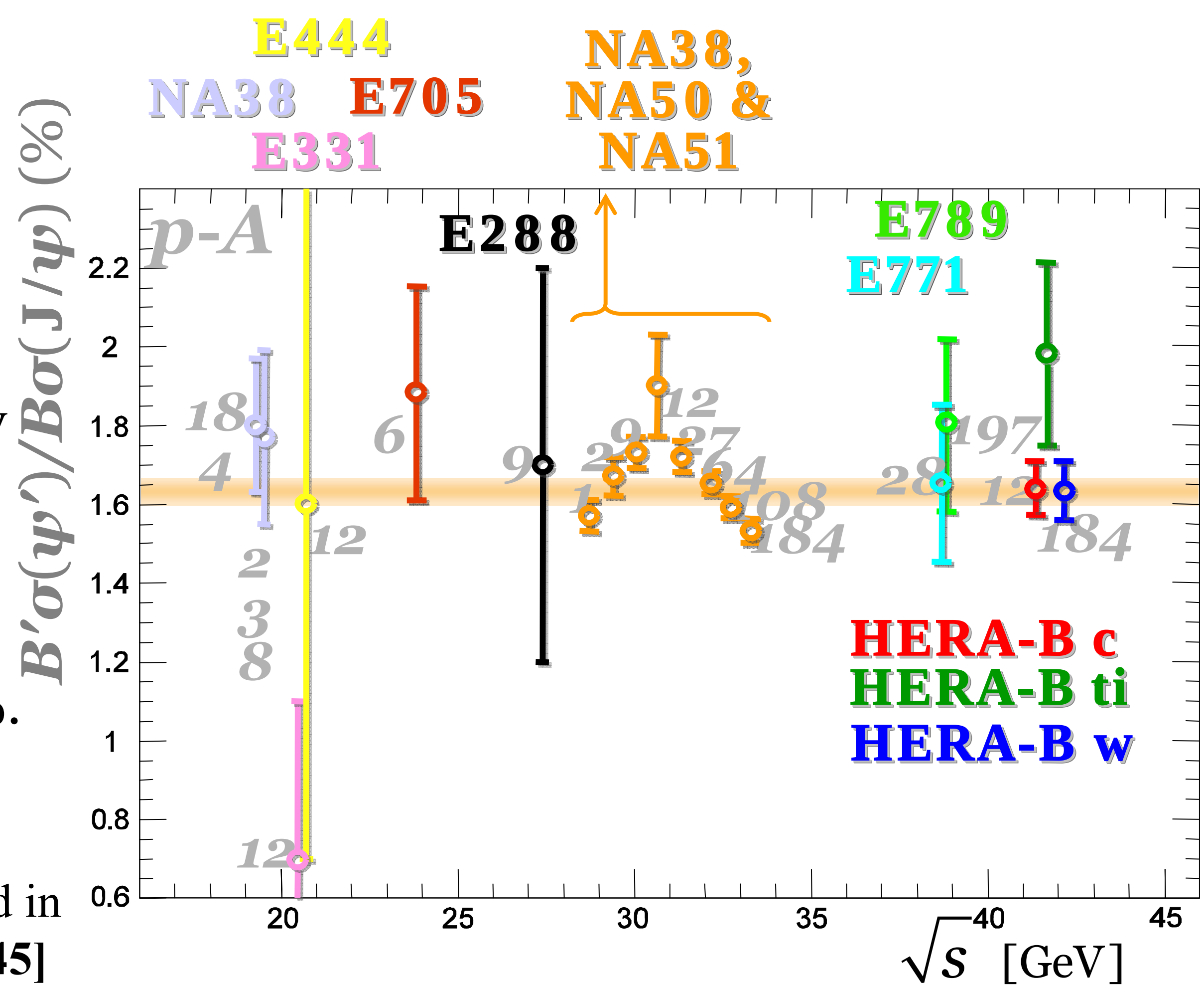
Combined results ($e^+e^- + \mu^+\mu^-$):

$$r_{\psi'}^{e^+e^-} = \frac{B_{\psi' \rightarrow l^+l^-}\ \sigma_{\psi'}}{B_{J/\psi \rightarrow l^+l^-}\ \sigma_{J/\psi}} = \begin{cases} 1.63 \pm 0.08\ \%(C) \\ 1.99 \pm 0.26\ \%(Ti) \\ 1.62 \pm 0.11\ \%(W) \end{cases}$$

- 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: $\chi_c \rightarrow J/\psi\ \gamma$, $J/\psi \rightarrow l^+l^-$

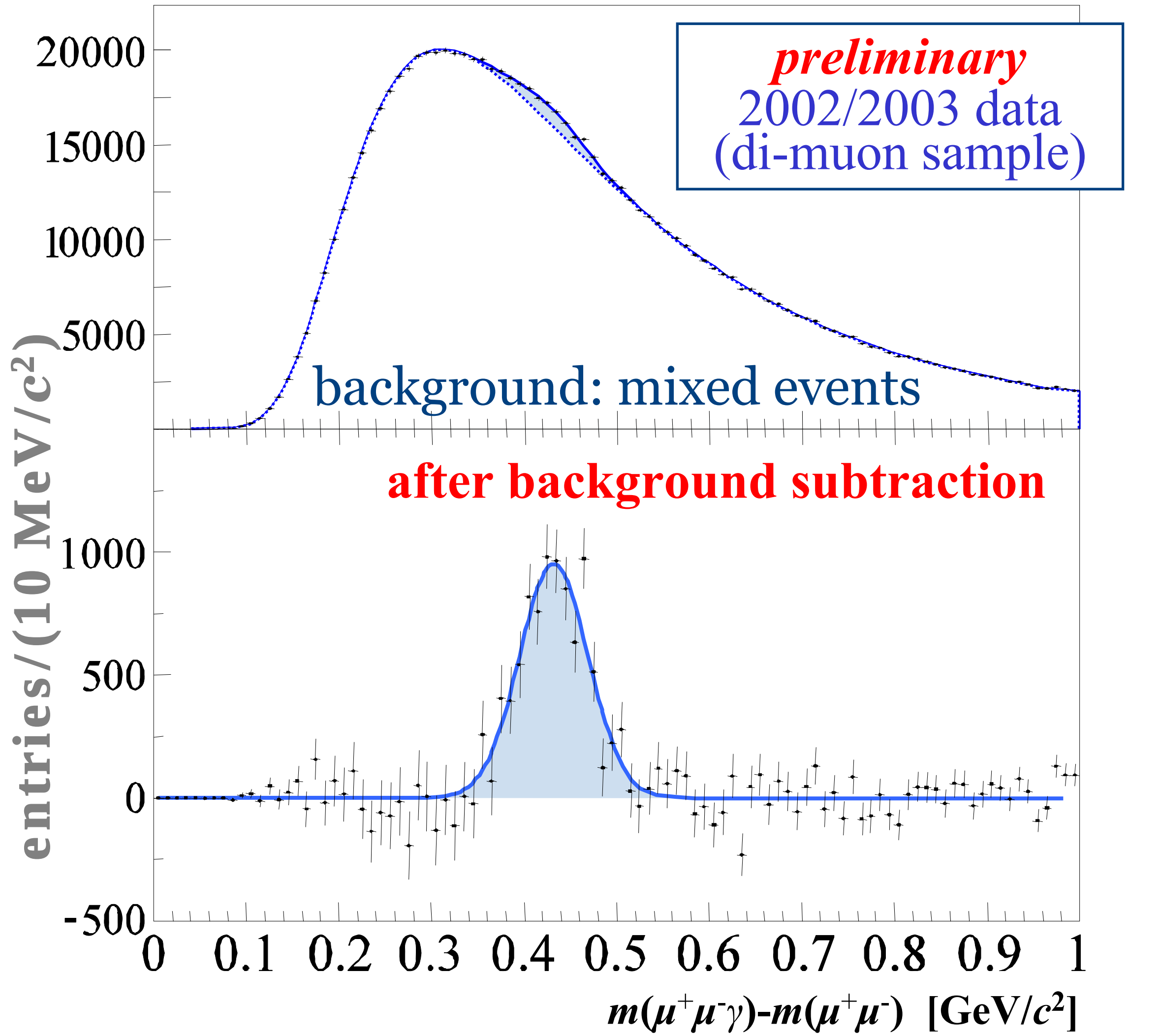
measurement:

- **fraction of J/ψ's from χ_c:**

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

- **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

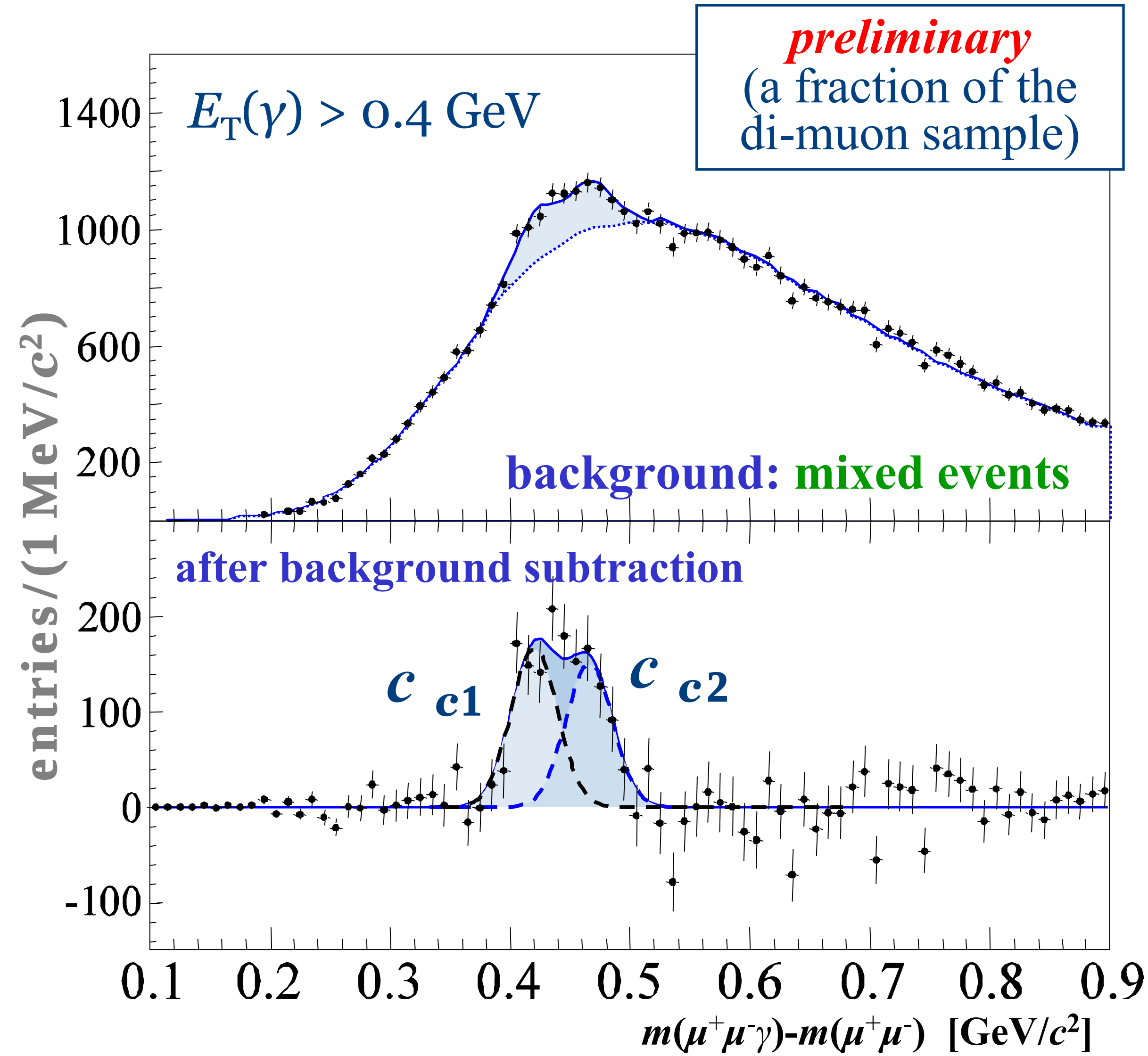
χ_{c1} - χ_{c2} Separation

further step:
separate different
states by varying
the selection cuts

measure the

χ_{c2}/χ_{c1}

production ratio

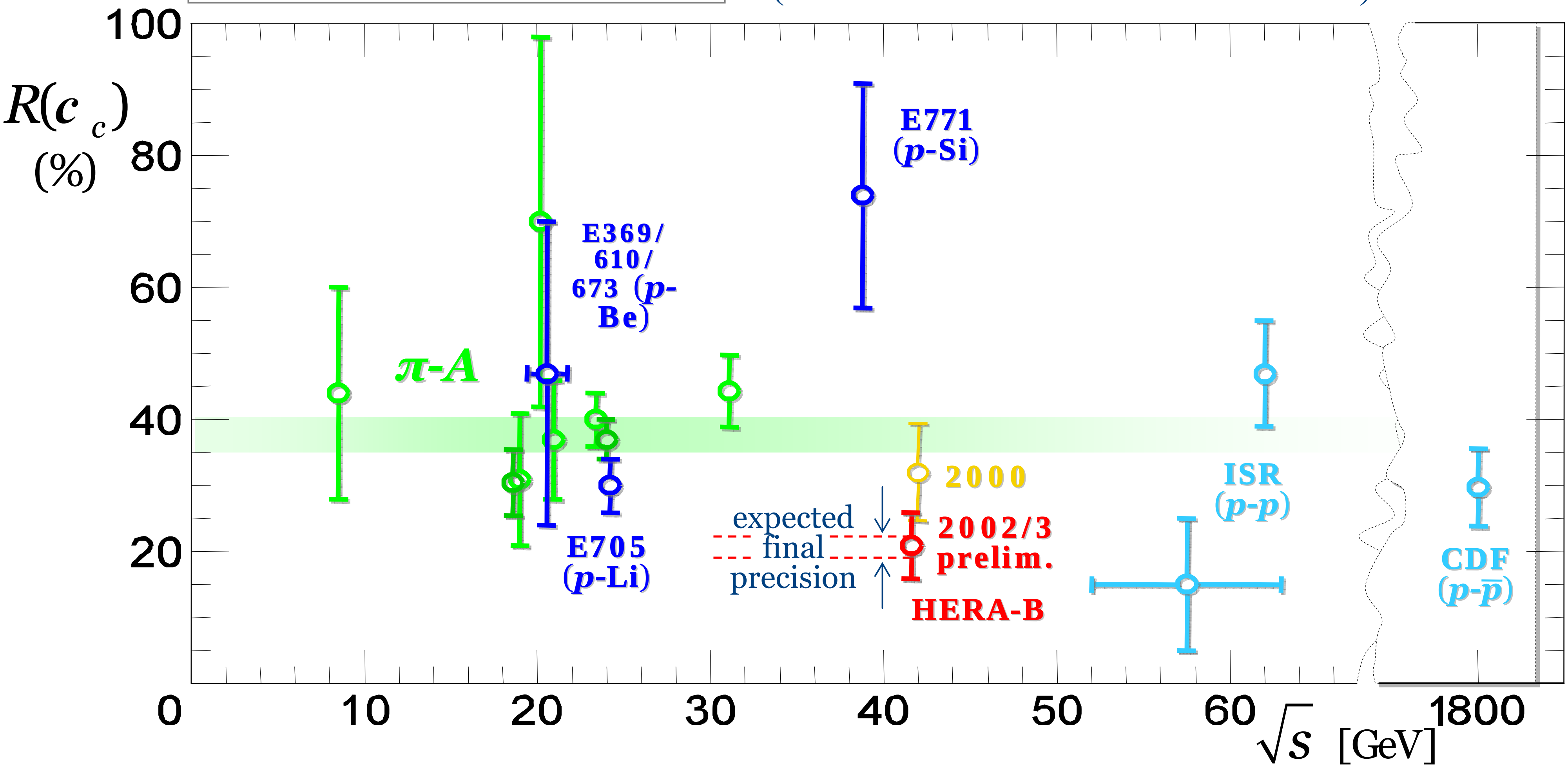


Production Cross Section Ratio R(χ_c)

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)



Summary

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/ψ A dependence demonstrate a flat behavior in this region
- **Fraction of χ_c and ψ(2S) yields relative to J/ψ**

Final results on J/ψ production, A-dependence, χ_c and ψ(2S) are/will be publisched 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 μs (proton bunches cross every 96 ns, 0.5 interactions/BX)

5 MHz

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

3 MHz

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

20 kHz

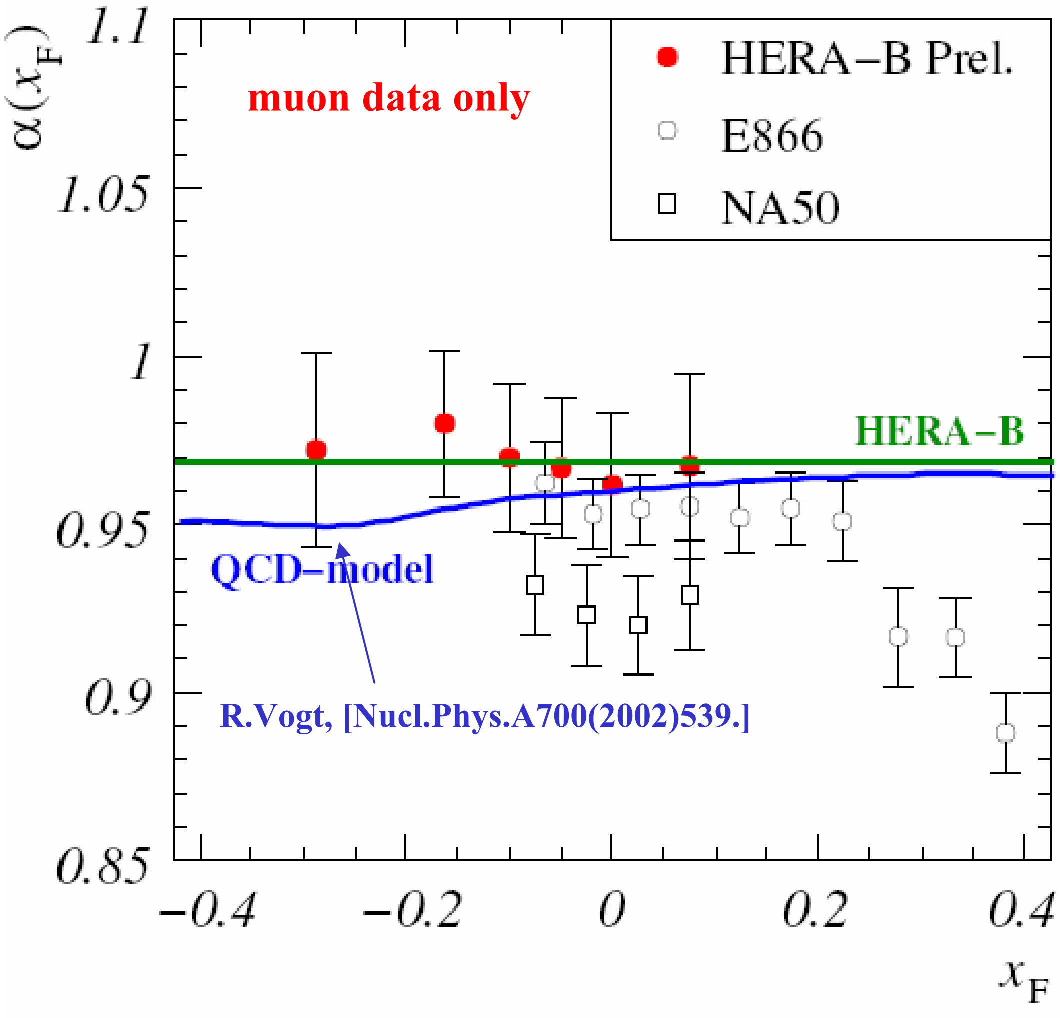
Second Level Trigger (SLT): FLT tracking confirmed, extrapolation to vertex detector, 2 track vertex fit (PC farm)

100 Hz

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

100 Hz

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

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