Studies on Charmonium production at HERA-B

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Outlook

- Charmonium production
- Detector
- Trigger and data sample
- $\psi(2S)/J/\psi$ production ratio
- J/ψ differential distributions p_T, x_F and $cos\theta$
- $\chi_c/J/\psi$ production ratio
- Conclusions

Charmonium production 1

NRQCD is the best approach for the charmonium production
good experimental confirmation at high energy (CDF $\sqrt{s} = 1.8$ TeV)
necessary measurements also at low energy ($\sqrt{s} \approx 10 - 100\ \mathrm{GeV}$)

- E379, E672/706, E705, E771, E772, E789, E866 ...
- results with pp, pA, πp, πA interactions
- lack of experimental or in some cases not clear panorama
  - no (or very few) results in the negative x_F range
  - few results on the J/ψ polarization
  - contradictory results on $R(\chi_c/J/\psi)$

Charmonium production 2

Further physics for J/ψ production in media

Charmonium production for pA is different with respect to pp

Nuclear effects in the initial and final (J/ψ formation) state

☞ Initial state:

- shadowing, parton energy loss
- transverse momentum broadening ($< p_T >$ dependence on A)

☞ Final state:

- nuclear absorption (dependence on x_F)
- Co-mover suppression, QGP effects (?)

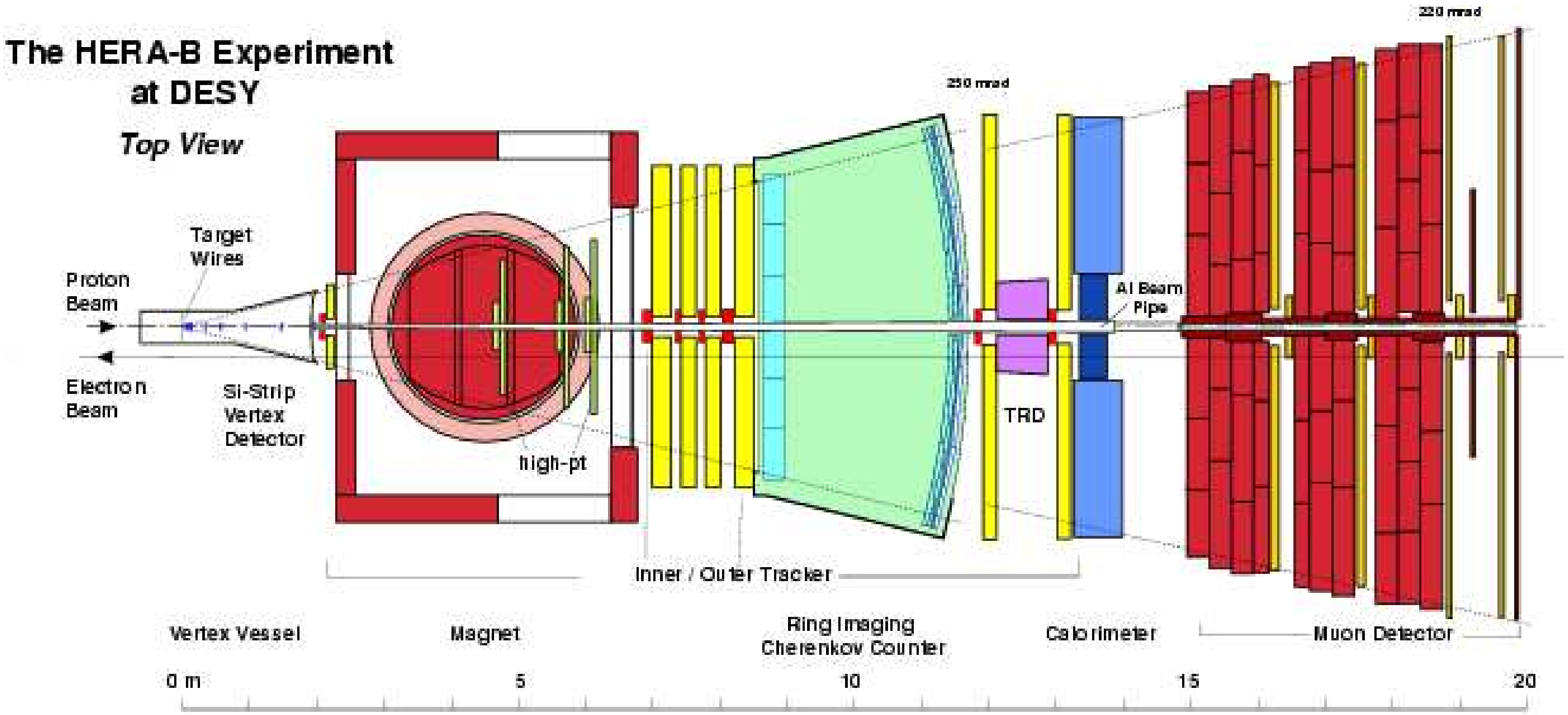
Necessary to study the differential distributions of J/ψ

Important to understand nuclear effects before interpreting ultra relativistic heavy ion collision (QGP)

HERA-B is in the ideal condition to study these effects

The HERA-B detector

Proton Beam of $920\ GeV/c$ ($\sqrt{s} = 41.6\ GeV$)



Large acceptance ($\rightarrow$ extend to negative x_F range)

detection of both electron and muon decay channels of J/ψ, $\psi(2S)$ ...

target materials: carbon,tungsten,titanium,aluminum

Dilepton trigger and data sample

2002/2003 data:

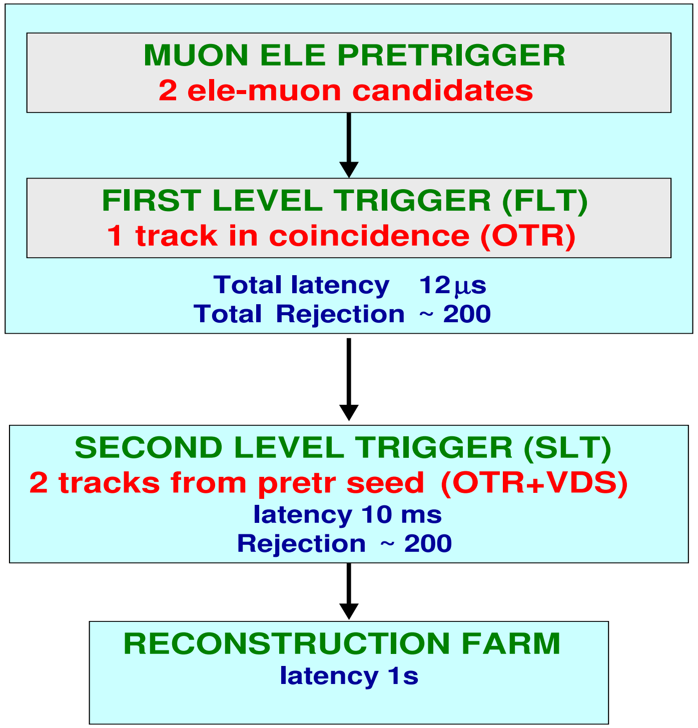
acquired from 5 to 10 MHz

rejection factor $\approx 10^4 - 10^5$

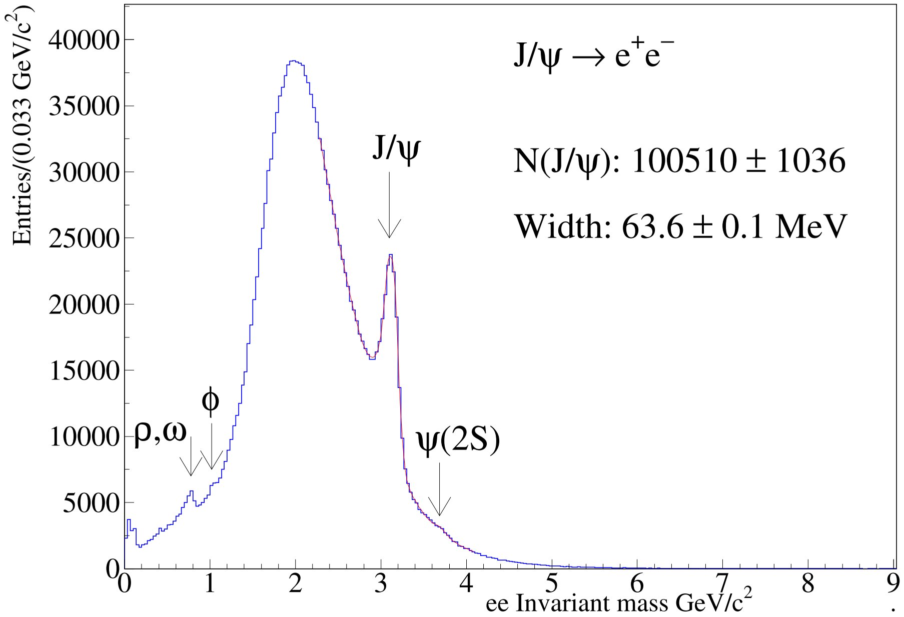
final rate $\approx$ 100 Hz

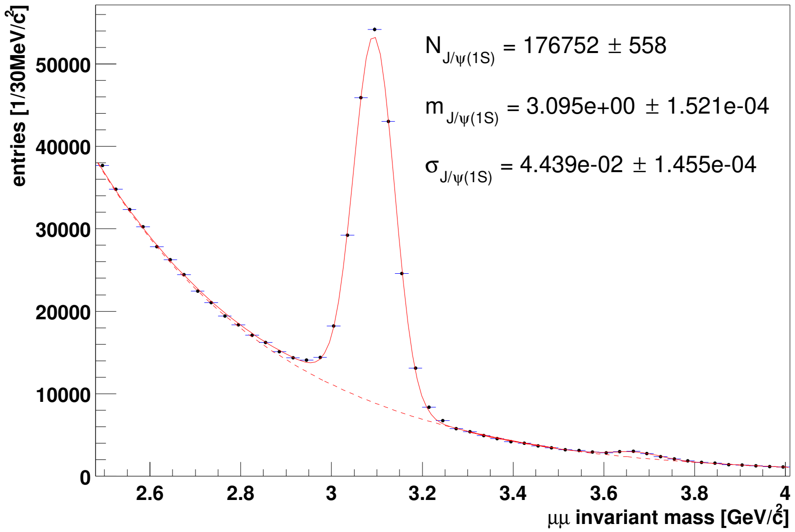
acquired $150 \cdot 10^6$ dilepton events

reconstructed $\approx$ 300K J/ψ



e^+e^- and $\mu^+\mu^-$ invariant mass





$\approx 80\%$ of the statistics for e^+e^- sample

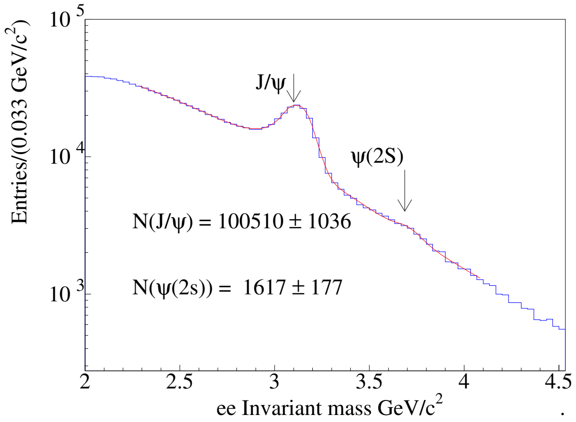
possibility to perform 2 independent analyses

high statistics and high quality J/ψ in both samples

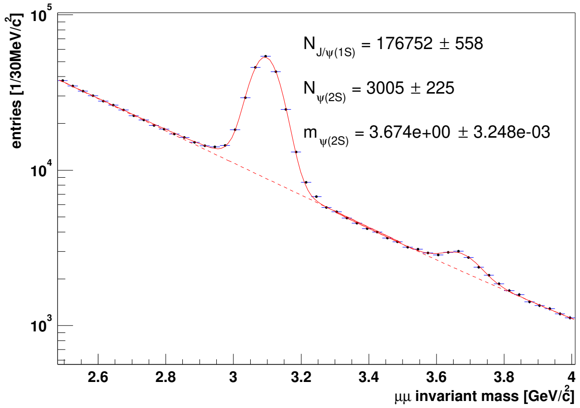
good starting point for charmonium analyses .

$\psi(2S)/\ J/\psi$ production ratio (R_u)

Electron analysis



Muon analysis



Preliminary

$R_u \ = \ 0.019 \pm 0.003$ C

analysis still ongoing on W

$R_u \ = \ 0.016 \pm 0.002$ C

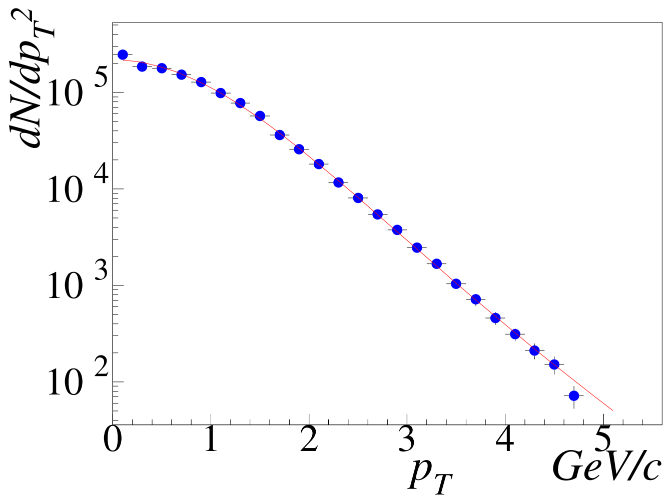
$R_u \ = \ 0.021 \pm 0.004$ W

by now not corrected for the acceptance (≈ 1)

Exp.	Interaction & p-momentum	R
E705	p-Li @ 300 GeV	0.0188 ± 0.0026
E789	p-Au @ 800 GeV	0.0161 ± 0.0010
E771	p-Si @ 800 GeV	0.0186 ± 0.0020

Statistical error comparable with the literature

p_T differential distribution



$p_T \rightarrow J/\psi$ transverse momentum

Energy in lab frame is 920 GeV

Arbitrary scale normalization

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

range $p_T < 4.5\,\mathrm{GeV}/c$

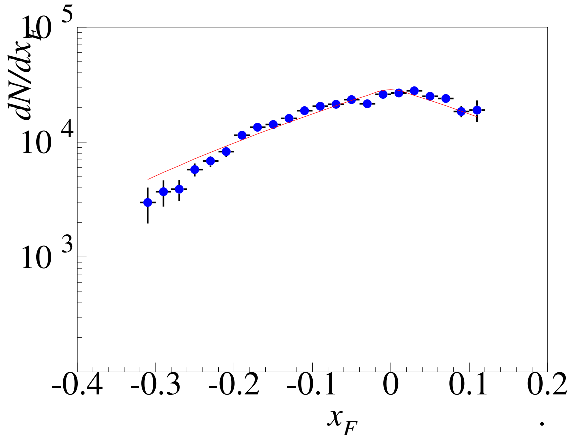
Preliminary results for $\langle p_T \rangle$ (GeV/c)

material	electron	muon	statistical error
C	1.22	1.22	$\approx 1\%$
W	1.29	1.30	$\approx 1\%$

Good agreement between $e^+e^-/\mu^+\mu^-$, wide p_T range, A dependence?

Exp.	Interaction & p-momentum	range (GeV/c)	$\langle p_T \rangle$ GeV/c
E771	p-Si @ 800 GeV	< 3.4	1.20 ± 0.01
E789	p-Au @ 800 GeV	< 2.6	1.29 ± 0.01

x_F differential distribution



$x_F \rightarrow J/\psi$ Feynman-x

Energy in lab frame is 920 GeV

Arbitrary scale normalization

$\frac{d\sigma}{dx_F} = \alpha \cdot (1 - |x_F|)^c$

range $-0.3 < x_F < 0.1$

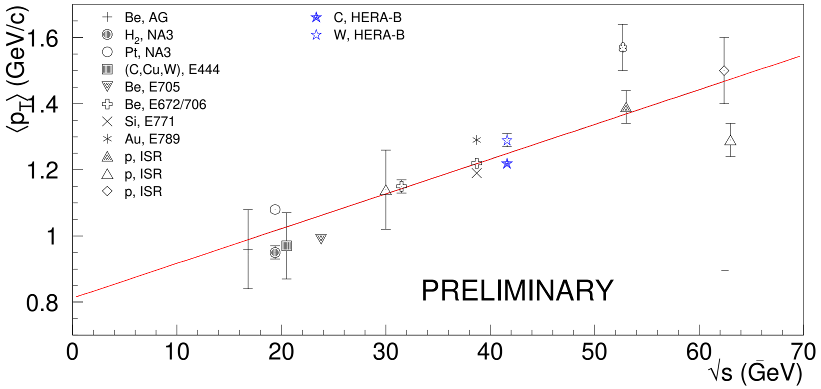
Preliminary analysis $\rightarrow$ range for c $[5 : 6.5]$ Expected stat. error $\leq 5\%$

Exp.	Interaction & p-momentum	range	c
E672/E706	p-Be @ 800 GeV	$0.0 < x_F < 0.6$	6.18 ± 0.16
E789	p-Be @ 800 GeV	$0.30 < x_F < 0.95$	5.32 ± 0.05
E771	p-Si @ 800 GeV	$-0.05 < x_F < 0.25$	6.54 ± 0.23
E789	p-Cu @ 800 GeV	$0.30 < x_F < 0.95$	5.21 ± 0.04
E789	p-Au @ 800 GeV	$-0.035 < x_F < 0.135$	4.91 ± 0.18

Not so clear experimental panorama and A dependence .

Negative x_F range is accessible .

$< p_T >$ and c dependence on $\sqrt{s}$

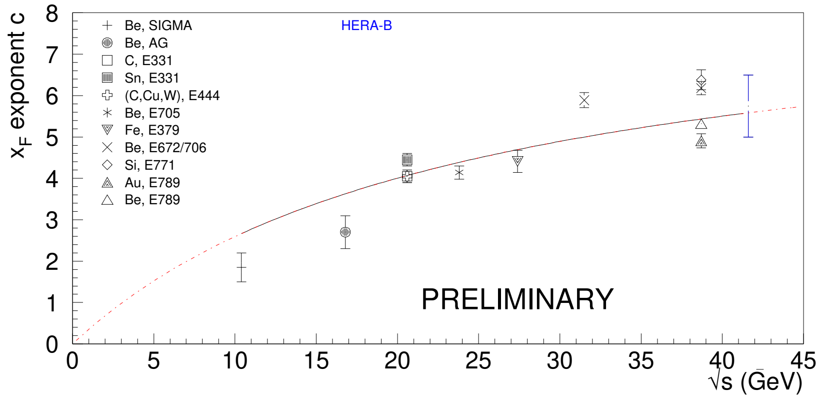


phenomenologic $< p_T >= A + B \cdot \sqrt{s}$

Fermilab-pub-91/62-E(1991) (E672/706 Coll)

$A = 0.813 \pm 0.014\,\mathrm{GeV}/c$

$B = 0.0105 \pm 0.0004c^{-1}$



phenomenologic $c = D/(1 + E/\sqrt{s})$

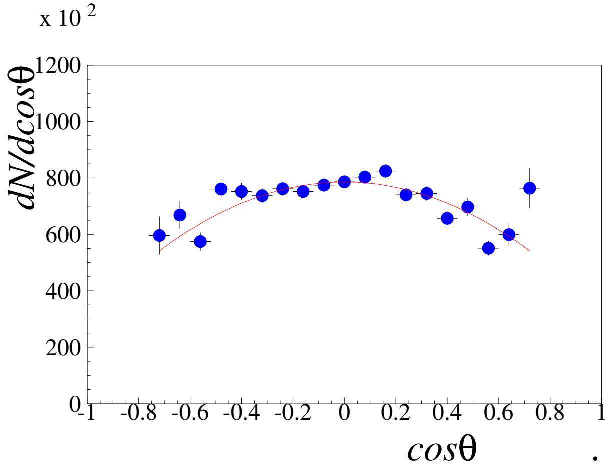
Fermilab-pub-91/62-E(1991) (E672/706 Coll)

$D = 8.80 \pm 0.41$

$E = 23.9 \pm 2.7\,\mathrm{GeV}$

precision of HERA-B competitive with previous results

$cos\theta$ differential distribution



θ $\rightarrow$ angle between the J/ψ direction in the lab frame and the positive lepton in the J/ψ rest frame
Arbitrary scale normalization

$$\frac{d\Gamma}{dcos\theta} = \gamma \cdot (1 + \lambda \cdot cos^2\theta)$$

λ is the J/ψ polarization parameter

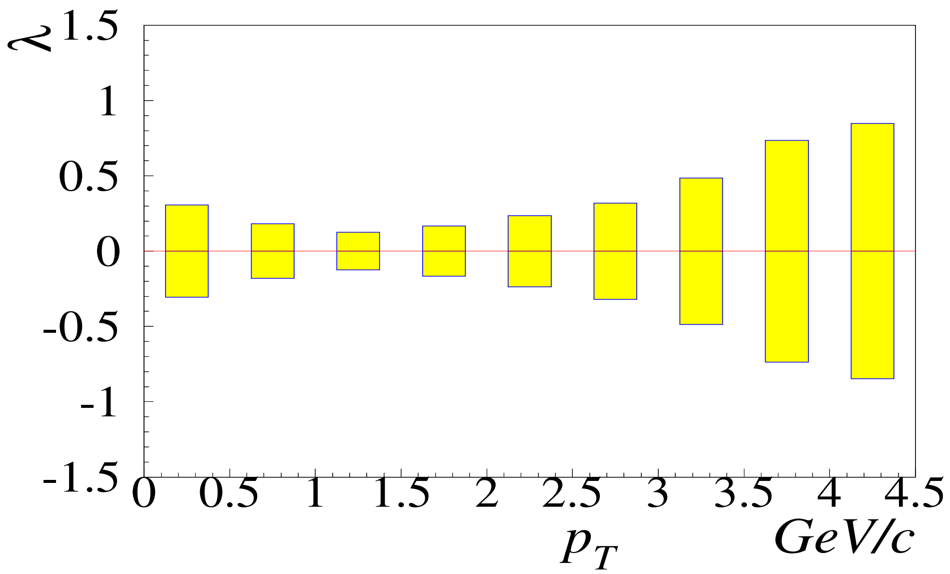
$\lambda = 0(1, -1)$ $\rightarrow$ J/ψ with no (transverse, longitudinal) polarization

Preliminary indications: λ significatively less than 0 Stat. error ≈ 0.1

More systematic studies needed

Exp.	Interaction & p-momentum	λ
E379	p-Fe @ 400 GeV	0.16 ± 0.08
E672/E706	p-Be @ 530 GeV	0.01 ± 0.15
E672/E706	p-Be @ 800 GeV	-0.11 ± 0.15
E771	p-Si @ 800 GeV	-0.09 ± 0.12

λ precision versus p_T



HERA-B sensitivity with the muon channel
Analysis just started

Theor. predictions on J/ψ polarization are model dependent (target p)

- CEM: $\lambda = 0$;
- NRQCD approach: $0 < \lambda < 0.1$ for $1.5 < p_T < 4\,\mathrm{GeV}/c$ (Ref.J.Lee,2000)
- CSM : $0.2 < \lambda < 0.4$ " "

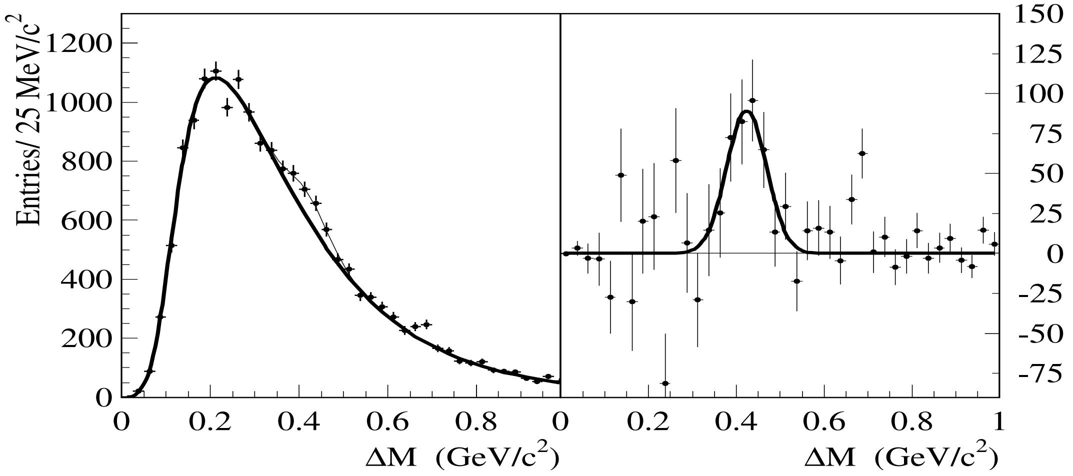
More experimental results and more theoretical predictions are needed

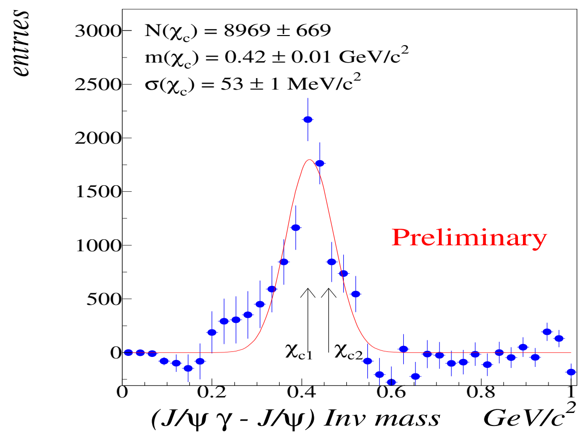
R_{χ_c} measurement

no distinction between χ_{c1} and χ_{c2} ($\Delta M = 46\,\mathrm{MeV}/c^2$)

Ratio J/ψ from χ_c $\boxed{R_{\chi_c} = \frac{N_{\chi c}}{N_{J/\psi}\cdot\epsilon_\gamma\cdot\epsilon_R} \approx \frac{N_{\chi c}}{N_{J/\psi}\cdot\epsilon_\gamma},\ \epsilon_R = \frac{\epsilon_{J/\psi from \chi c}}{\epsilon_{J/\psi}}}$

$\chi_c \rightarrow J/\psi\gamma \rightarrow \mu^+\mu^-\gamma$ and $\rightarrow e^+e^-\gamma$





2000 data ($N(\chi_c) \approx 400$) $R_{\chi_c} = 0.32 \pm 0.07$ Phys.Lett.B561(2003) 61,

2002/2003 data statistics increase by a factor ≈ 30 (analysis ongoing)

R_{χ_c} experimental situation and expectations

Exp.	Interaction & $\sqrt{s}$	R_{χ_c}
E610	p-Be @ 19.4-21.7 GeV	0.47 ± 0.23
E705	p-Li @ 23.8 GeV	0.30 ± 0.04
E771	p-Si @ 38.8 GeV	0.74 ± 0.17

No clear experimental panorama

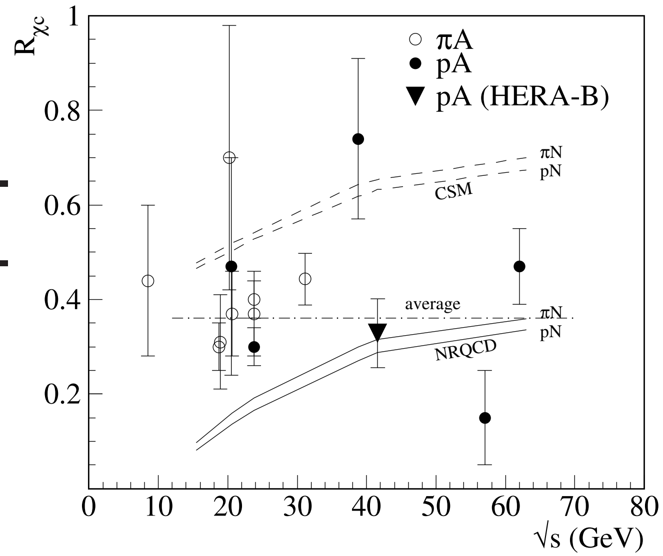
expectations at $\sqrt{s} = 41.6\,\mathrm{GeV}$

	NRQCD	CSM	CEM
R_{χ_c}	0.3 [1]	0.6 [2]	constant [3]

[1] Phys.Rev.D53(1996) 6203

[2] Phys.Lett.B102(1981) 364, Z.Phys.C19(1983)251

[3] Phys.lett.B67(1977) 217, B390(1997) 323 ...



2000 HERA-B result agrees with NRQCD expectations.

More precise result in 2002/2003 ($\rightarrow$ more stringent tests) .

future perspectives on charmonium

HERA-B has the possibility to perform also further charmonium studies, as:

- study of the A, p_T and x_F dependence of the polarization
- study of the p_T, x_F and $cos\theta$ differential distributions for χ_c
- double charmonium production (and $(c\bar{c})D\overline{D}$ search)
- h_c search
- χ_{c1}/χ_{c2} production ratio
- diffractive charmonium production

Conclusions

- HERA-B will provide important results for the charmonium studies
  - statistics and resolutions comparable or better with respect to other experiments (except E866 $\approx 2MJ/\psi$)
  - analyses in 2 independent channels $\rightarrow$ checks on systematics
  - wider ranges (x_F , p_T ...)
- Preliminary results on p-A @ 920 GeV(carbon, tungsten)
  - $\psi(2S)/ J/\psi$ production ratio
  - p_T, x_F and $cos\theta$ differential distributions
  - $\chi_c/ J/\psi$ ratio
- Future steps
  - process full statistics, finalize analysis, determine systematics
- Inputs from theoreticians are welcome
  - detailed comparison with expectations will be possible