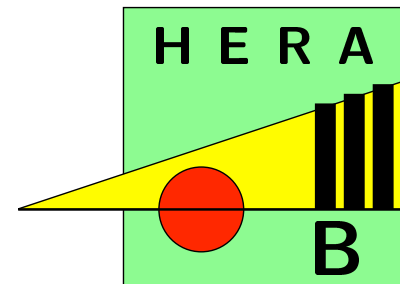


*XIII International Workshop on Deep Inelastic Scattering
Madison, Wisconsin, April 27 – May 1, 2005*

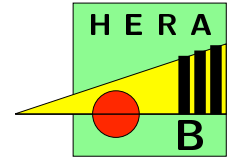
Charm and Beauty Production at HERA-B



Ulrich Husemann
for the HERA-B Collaboration
University of Rochester/DESY

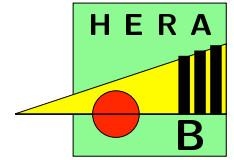


Outline of the Talk



- ▶ HERA–B detector and trigger
- ▶ Charmonium production
- ▶ Beauty production
- ▶ Summary

The HERA-B Detector



Muon Detector
4 layers of gas pixel chambers (inner) and MWPC with cathode pad readout (outer), pad-coincidence pretrigger

Inner/Outer Tracker
7 layers of GEM-MSGCs (inner) and honeycomb drift chambers (outer)

Wire Target
2 stations, 4 wires each (C, Ti, W)

920 GeV/c Protons

Silicon Vertex Detector
8 double-layers of double-sided Si-microstrips

Magnet

RICH
C₄F₁₀ radiator, multianode PMT focal plane

ECAL
W/Pb-scintillator sampling calorimeter, shashlik readout, cluster pretrigger

20 m

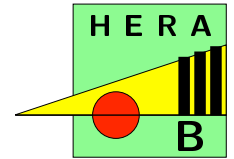
5

0 m

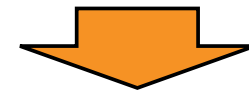
DIS20

charm and Beauty Production at HERA-B

The Dilepton Trigger



HERA-B detector: data are read out and buffered for 10 μ s
(proton bunches cross every 96 ns)



10 MHz

Pretriggers: ECAL cluster or hit coincidence in
muon detector as trigger seed (custom hardware)



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

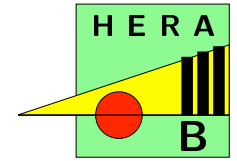


150 kHz

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



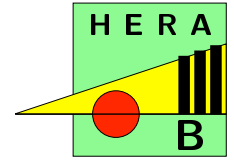
100 Hz



Data Sample

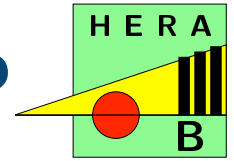
- ▶ Data-taking period: **October 2002 – February 2003**
- ▶ **Dilepton trigger**: require ≥ 2 electrons or muons
 - Trigger performance: $> 1,000$ J/ψ per hour
 - Sample for charmonium & beauty studies:
 - 300,000 J/ψ
 - 15,000 χ_c
 - 3,500 $\psi(2S)$
- ▶ **Minimum-bias trigger**: require minimum activity in RICH and/or ECAL
 - DAQ performance: $> 1,000$ events per second
 - 200 million events total
 - Analysis of J/ψ and open charm production
 - Strangeness and hyperon production, pentaquarks, ...

Outline of the Talk



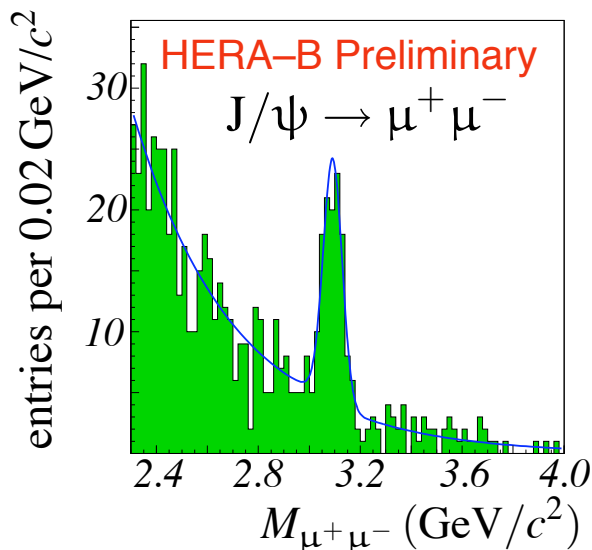
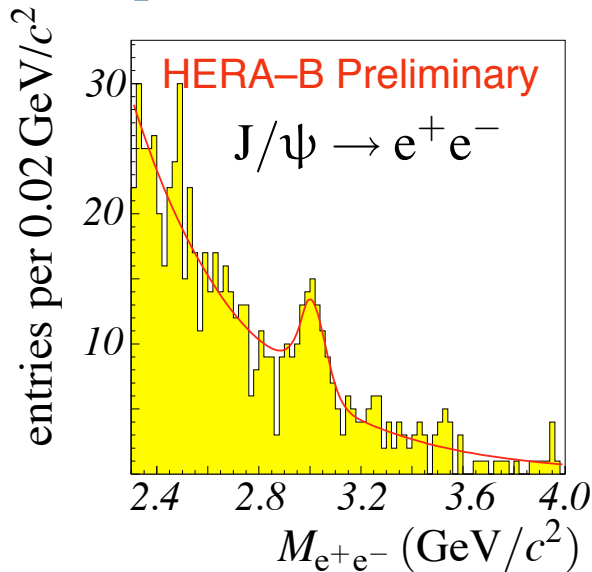
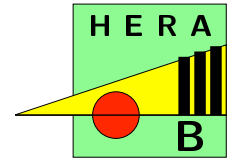
- ▶ HERA–B detector and trigger
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Why Charmonium Production?

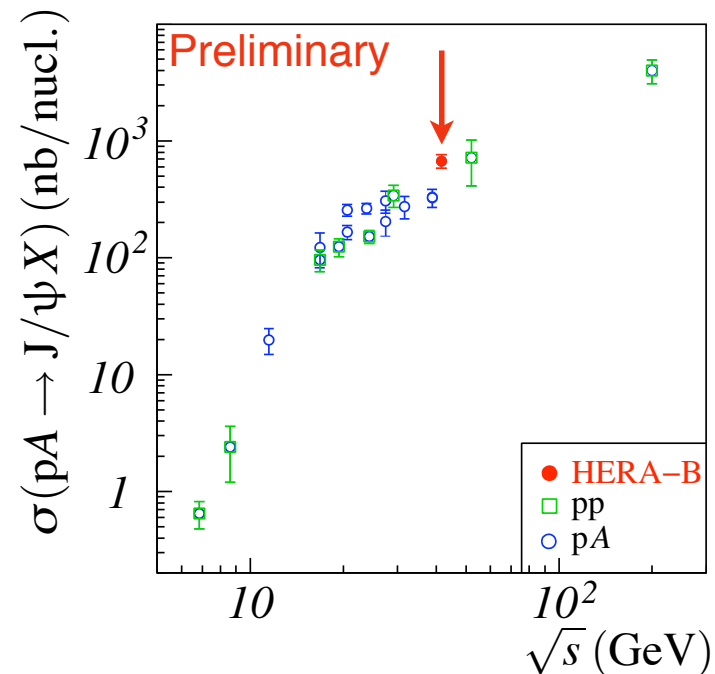


- ▶ Theoretical framework for calculation of charmonium production: **nonrelativistic QCD** (NRQCD)
 - Test **universality** of NRQCD matrix elements
- ▶ Proton-nucleus (pA) interactions: **nuclear effects**
 - **Initial state effects**, e.g. modified parton distributions
 - **Final state effects**, e.g. absorption of $c\bar{c}$ inside nucleus
 - Effects depend on charmonium **kinematics**: x_F / p_T
- ▶ HERA-B's strong points:
 - **Dedicated triggers** for muon and electron pairs
 - Large **angular acceptance**: $-0.35 < x_F < 0.10$; $p_T < 5 \text{ GeV}/c$ ($x_F < -0.1$ **previously unexplored** in fixed-target expts.)

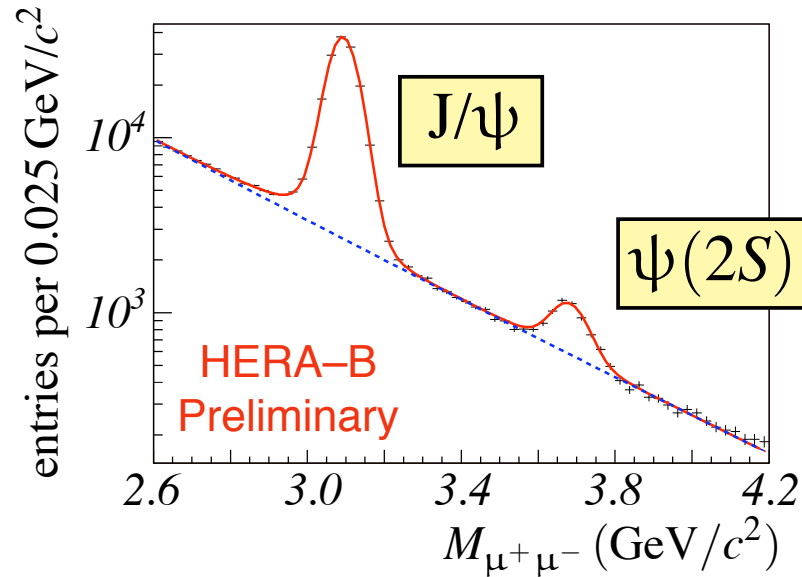
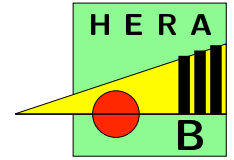
J/ ψ Production Cross Section



- ▶ J/ ψ signals in minimum-bias data
- ▶ Systematic studies underway
- ▶ Plan: use fit to available J/ ψ cross section data as normalization for other heavy flavor cross section measurements



$\psi(2S)$ Production

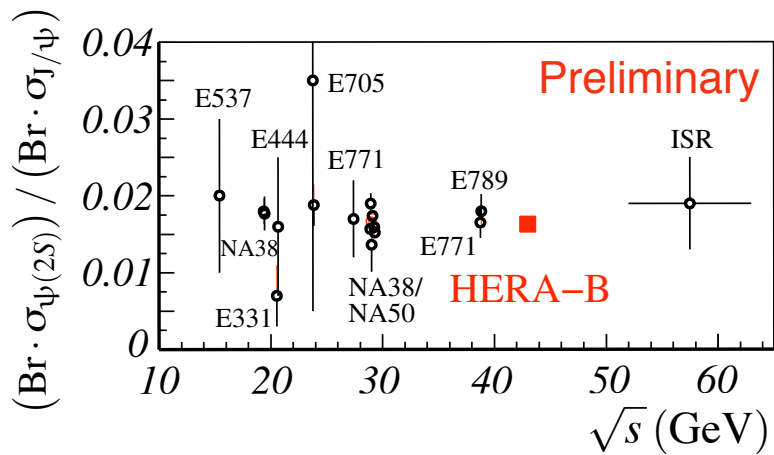


$$R_{\psi(2S)} = \frac{\text{Br}(\psi(2S) \rightarrow \ell^+ \ell^-) \cdot \sigma_{\psi(2S)}}{\text{Br}(J/\psi \rightarrow \ell^+ \ell^-) \cdot \sigma_{J/\psi}}$$

$$= \frac{N_{\psi(2S)}}{N_{J/\psi}} \cdot \frac{\epsilon_{J/\psi}}{\epsilon_{\psi(2S)}}$$

Invariant mass fits MC simulation

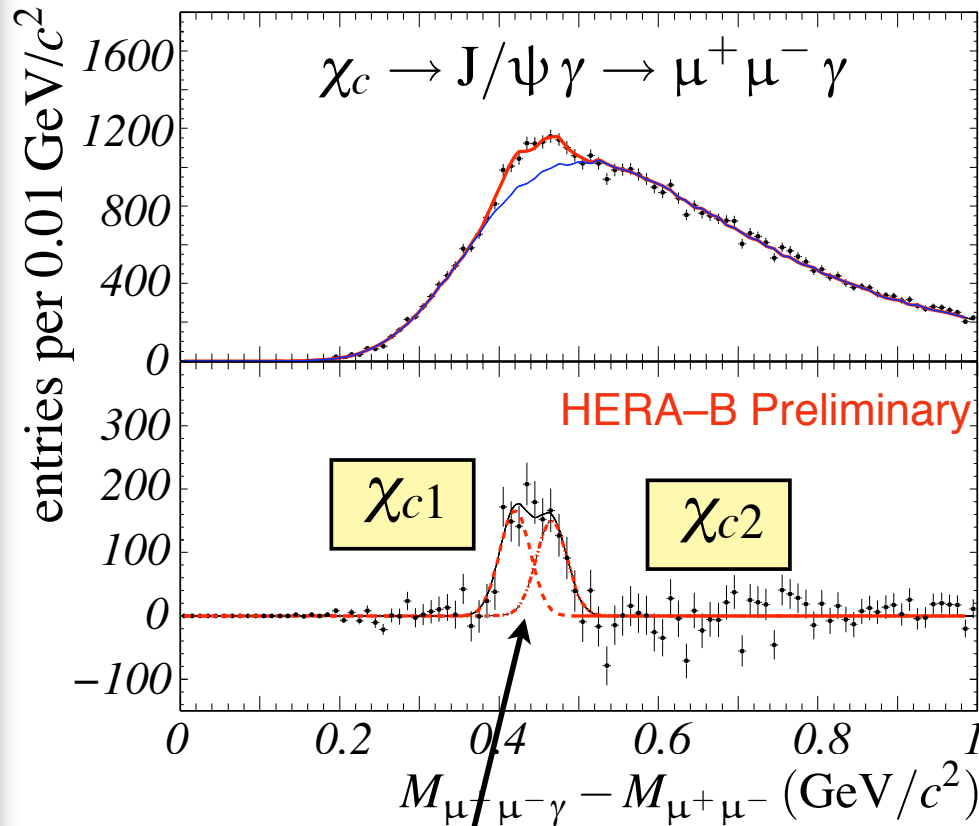
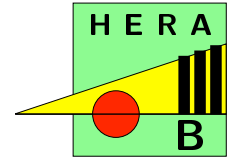
- ▶ Measure $\psi(2S)$ production relative to J/ψ production, **preliminary** results:



$R_{\psi(2S)}$	$\mu^+ \mu^-$	$e^+ e^-$
C	0.017 ± 0.001	0.016 ± 0.002
W	0.016 ± 0.002	0.018 ± 0.004

- ▶ Working on systematics

χ_c Production



New: separation of χ_{c1} vs. χ_{c2}

▶ Event selection:

- 2 leptons from J/ψ decay
- Photon with $E_T > 0.4 \text{ GeV}$

Key measurement:
fraction of J/ψ from χ_c
(2002/3 preliminary):

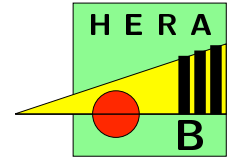
$$R_{\chi_c} = 0.21 \pm 0.05(\text{stat.})$$

Published result from 2000 data:

$$R_{\chi_c} = 0.32 \pm 0.06(\text{stat.}) \\ \pm 0.04(\text{syst.})$$

I. Abt *et al.*, Phys. Lett. **B561** (2003) 6

J/ψ: Nuclear Effects



- ▶ Operate ^{12}C and ^{184}W targets **simultaneously**
→ relative measurement → systematics cancel out
- ▶ Standard parametrization of nuclear effects:

$$\sigma_{pA} = \sigma_{pN} \cdot A^\alpha$$

where: A atomic mass number, $\sigma_{pA} = N_A / (\mathcal{L}_A \cdot \epsilon_A)$

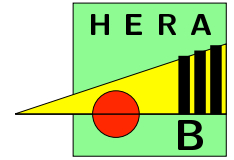
$$\alpha = \frac{1}{\log(A_W/A_C)} \log \left(\frac{N_W}{N_C} \cdot \frac{\mathcal{L}_C}{\mathcal{L}_W} \cdot \frac{\epsilon_C}{\epsilon_W} \right)$$

I. Ratio of J/ψ yields: fits to invariant mass spectra

II. Ratio of luminosities: count primary vertices per wire

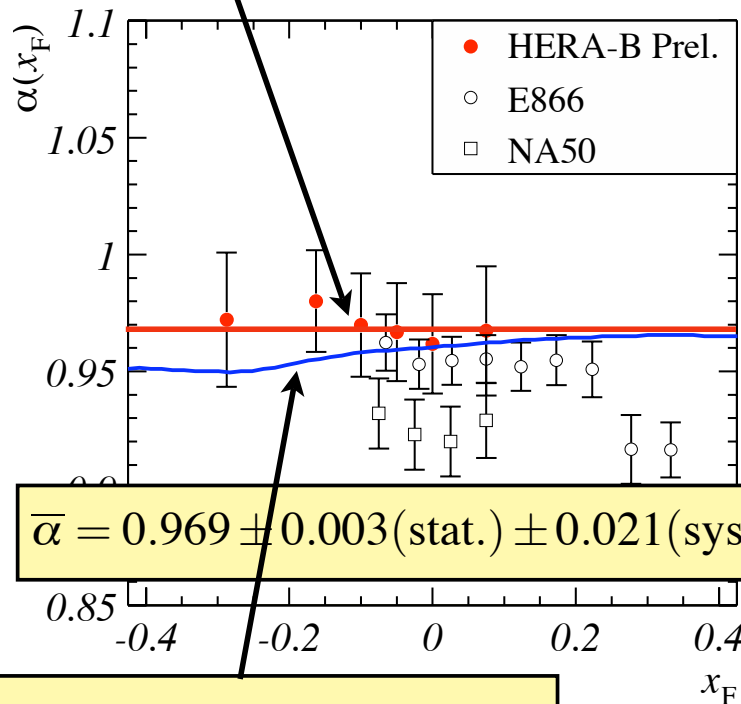
III. Ratio of efficiencies: detailed detector/trigger simulation

Nuclear Effects: Results



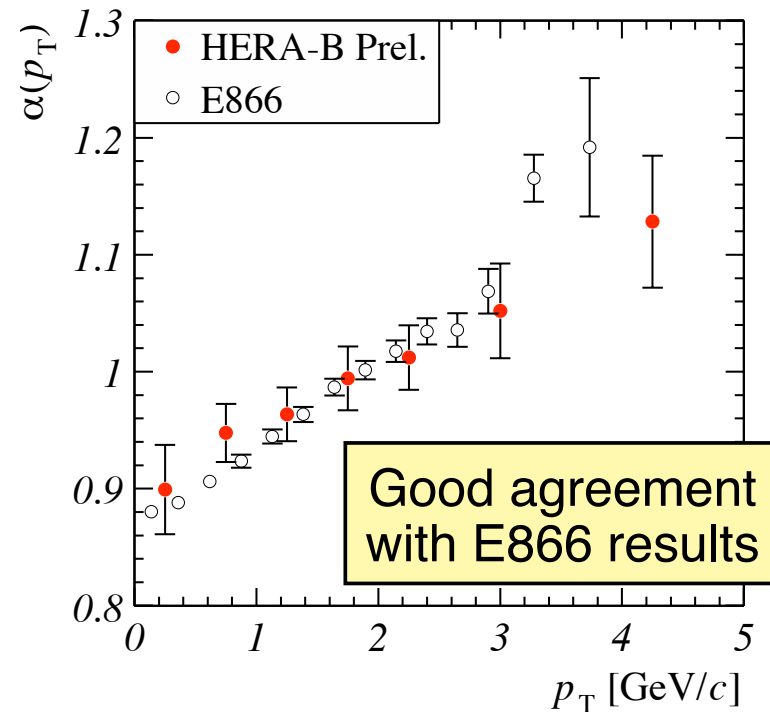
First measurement at $x_F < -0.1$, constant small suppression

Dimuon channel, full data-set
(to be combined with electron result)



$\bar{\alpha} = 0.969 \pm 0.003(\text{stat.}) \pm 0.021(\text{syst.})$

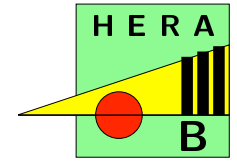
Good agreement with final state absorption model
R. Vogt, Nucl. Phys. **A700** (2002) 539



Good agreement with E866 results

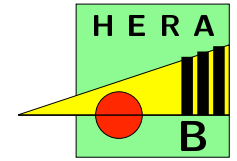
UH, DESY-THESIS-2005-05 (2005)
M. Leitch *et al.* (E866), Phys. Rev. Lett. **84** (2000) 3256
B. Alessandro *et al.* (NA50), Eur. Phys. J. **C33** (2004) 31

Outline of the Talk



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B Production Cross Section

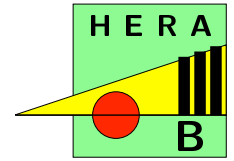


- ▶ Beauty production at fixed-target experiments **close to kinematic threshold**: large theoretical and experimental uncertainties
 - Experiments: low statistics, large systematic uncertainties
 - Theory: soft gluon resummation, b quark mass
- ▶ HERA-B: **inclusive** channel $pA \rightarrow b\bar{b} \rightarrow J/\psi X \rightarrow \ell^+ \ell^- X$
 - Measure number of J/ψ from B meson decays **relative to prompt J/ψ production** inside kinematic acceptance

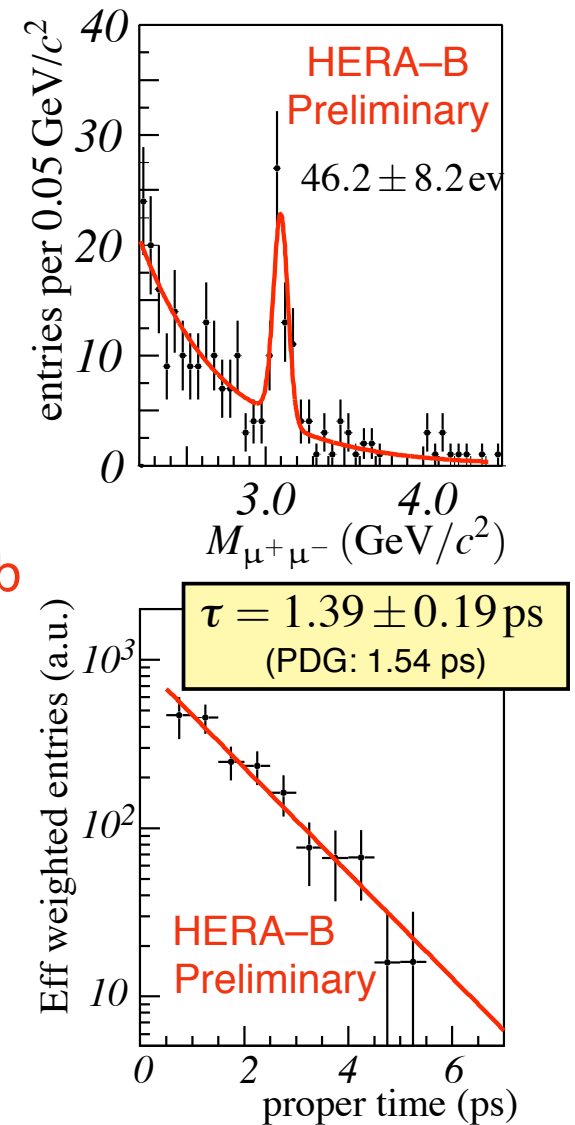
$$R_{b\bar{b}} = \frac{\Delta\sigma_{b\bar{b}}}{\Delta\sigma_{J/\psi}} = \epsilon \cdot \frac{N_{b\bar{b} \rightarrow J/\psi X}}{N_{\text{prompt } J/\psi}}$$

↑
branching fractions, relative
efficiencies, nuclear dependence

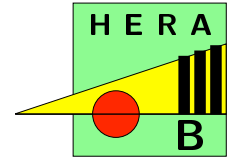
Detached Vertex Analysis



- ▶ Mean flight path of B mesons at HERA-B energies: 8 mm
 - Selection of B candidates:
 - Significance of J/ψ **displaced vertex**
 - Significance of J/ψ **impact parameter** to target wire
 - Main backgrounds:
 - **Prompt J/ψ** and **double semileptonic b and c decays**: MC simulation
 - **Combinatorial** background: compare background **upstream of target vs. downstream** of target
 - Confirmation of B flavor:
 - Fit to **B lifetime**
 - Require **third track** from decay vertex



B Cross Section: Results



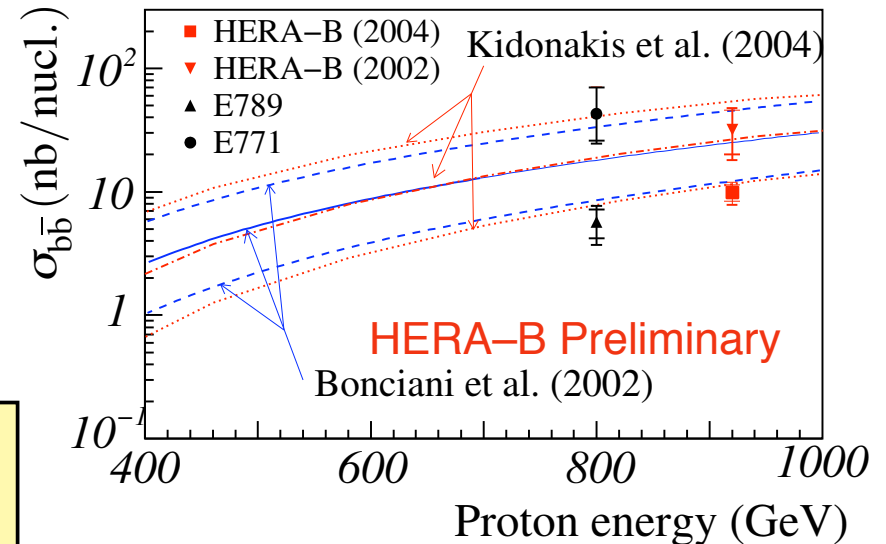
- ▶ **Weighted average** of results from 2000 (I Abt et al., Eur. Phys. J. **C26** (2003) 345) and 2002/3 data-taking periods:

$$\frac{\Delta\sigma_{b\bar{b}}}{\Delta\sigma_{J/\psi}} = 0.033 \pm 0.005(\text{stat.}) \pm 0.004(\text{syst.})$$

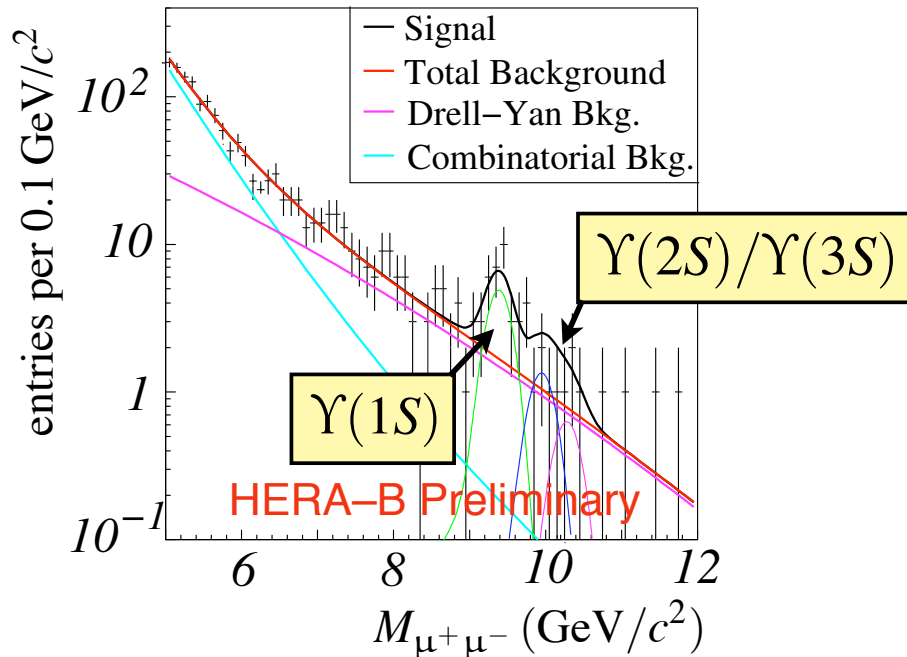
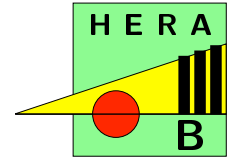
- ▶ Extrapolation to **full cross section**:

- Extrapolation to full phase-space: theory
- $\sigma_{J/\psi} = 352 \text{ nb/nucl.}$ (average of E789 & E771, rather low, currently under investigation)

$$\sigma_{b\bar{b}} = 9.9 \pm 1.5(\text{stat.}) \pm 1.4(\text{syst.}) \text{ nb/nucl.}$$



Y Production

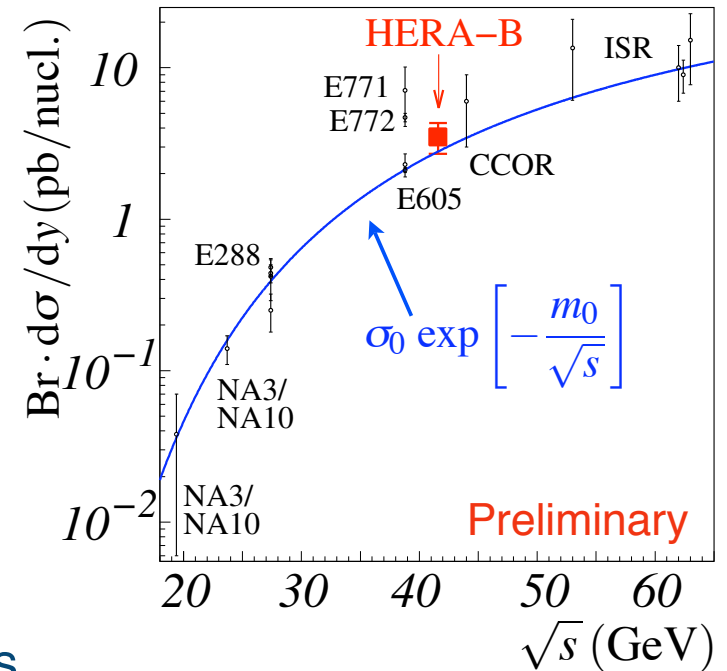


Measure relative to $\sigma_{J/\psi} = 352 \text{ nb/nucl.}$

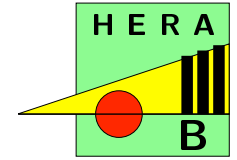
$$\text{Br}(\Upsilon \rightarrow \ell^+ \ell^-) \cdot \left. \frac{d\sigma}{dy} \right|_{y=0} = 3.5 \pm 0.8 \text{ pb/nucl.}$$

- Data compatible with **no nuclear effects**
- Drell-Yan: consistent with previous expts.

Test quarkonium production models and nuclear effects also in $b\bar{b}$ production



Summary & Outlook



- ▶ HERA–B has **finished** data-taking
- ▶ Analysis of data taken in 2002/2003 **well-advanced**
- ▶ **Charmonium production:**
 - J/ψ production and nuclear dependence for $x_F < -0.1$
 - $\psi(2S)$ -to-J/ψ production ratio
 - Fraction of J/ψ from χ_c decays
- ▶ **Beauty production:**
 - B production cross section from inclusive $b\bar{b} \rightarrow J/\psi X$
 - Υ production cross section

Stay tuned –

Many of these results are to be published soon