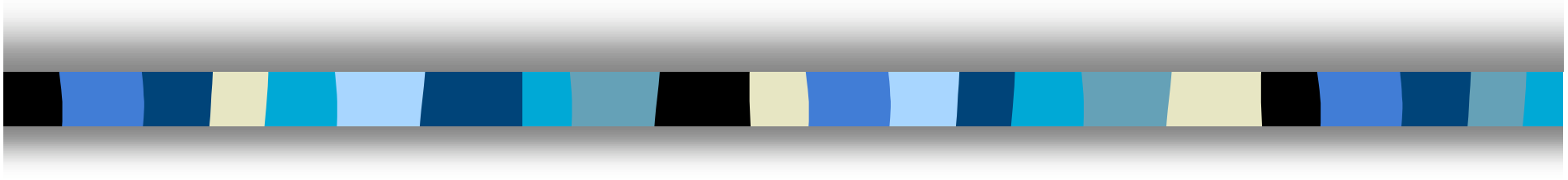
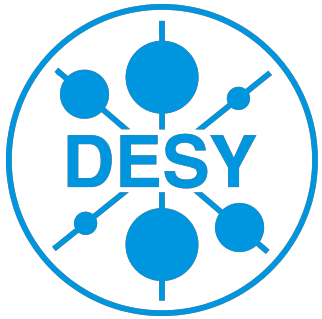
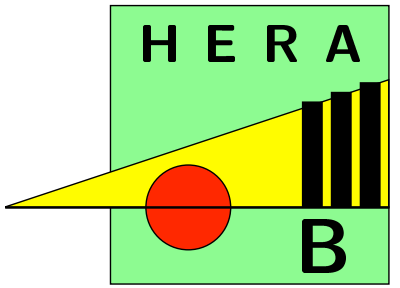
XIII International Workshop on Deep Inelastic Scattering
Madison, Wisconsin, April 27 – May 1, 2005

Charm and Beauty Production at HERA–B

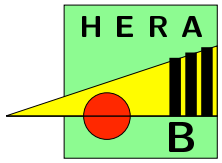




Ulrich Husemann
for the HERA–B Collaboration
University of Rochester/DESY



Outline of the Talk



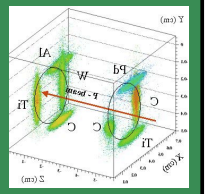
- HERA–B detector and trigger
- Charmonium production
- Beauty production
- Summary

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

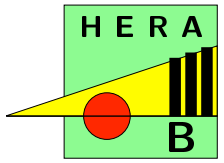
Magnet

RICH
C_4F_{10} radiator, multianode PMT focal plane

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

20 m 5 0 m

The Dilepton Trigger



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

10 MHz

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

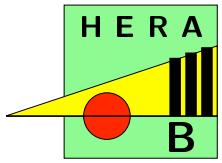
First Level Trigger (FLT): Track trigger in hardware using tracking detectors behind magnet, seeding by pretriggers

150 kHz

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

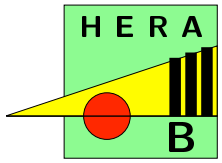
100 Hz

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 ψ(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



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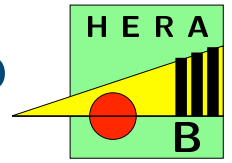
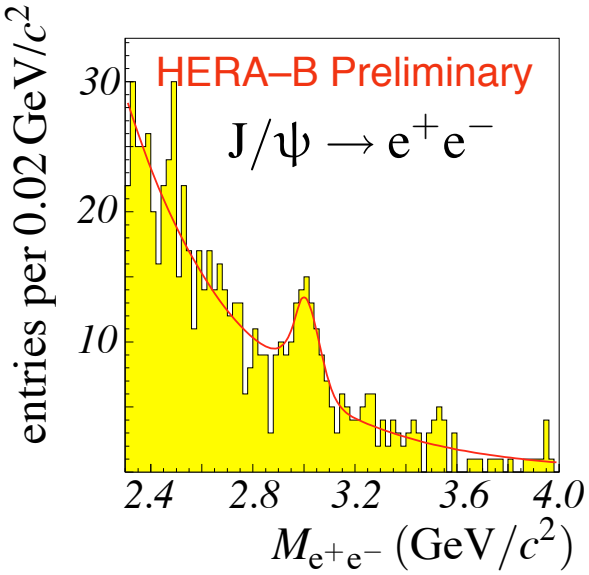
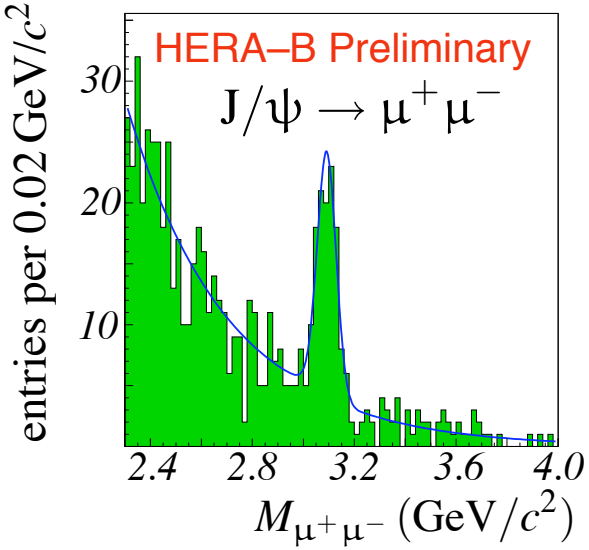
Why Charmonium Production?



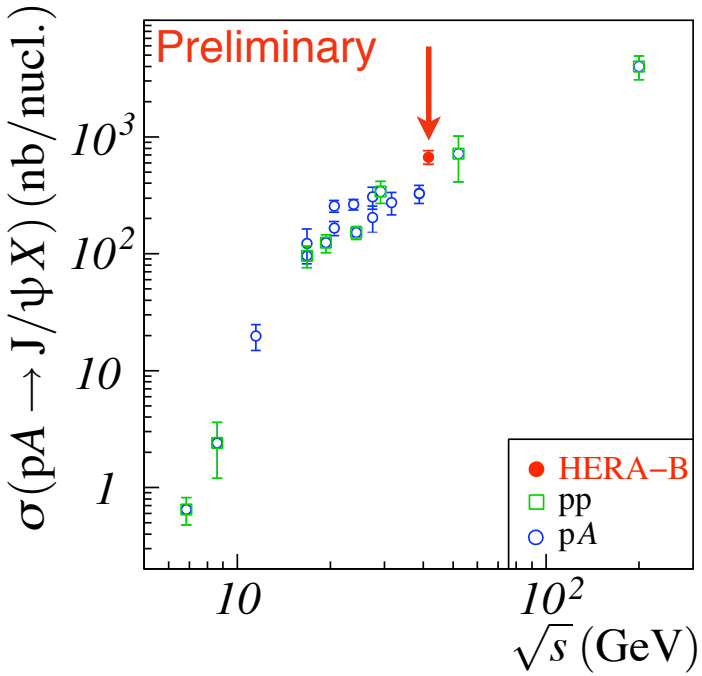
- Theoretical framework for calculation of charmonium production: nonrelativistic QCD (NRQCD)
  - Test universality of NRQCD matrix elements
- Proton-nucleus (p*A*) interactions: nuclear effects
  - Initial state effects, e.g. modified parton distributions
  - Final state effects, e.g. absorption of $c\bar{c}$ 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: $-0.35 < x_F < 0.10$; $p_T < 5$ GeV/c ($x_F < -0.1$ previously unexplored in fixed-target expts.)

J/ψ Production Cross Section

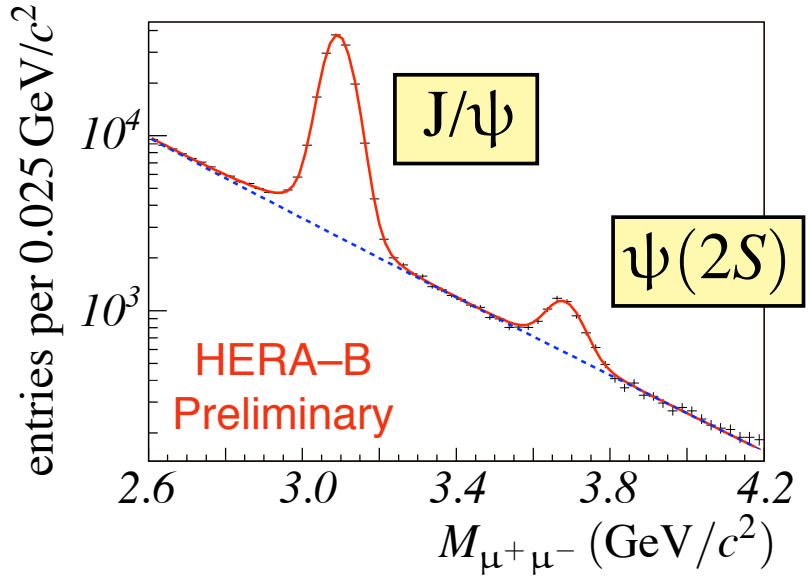


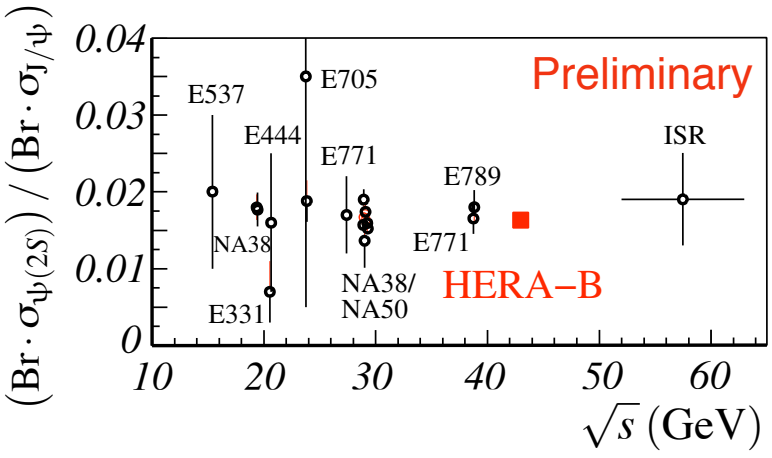


- J/ψ signals in minimum-bias data
- Systematic studies underway
- Plan: use fit to available J/ψ cross section data as normalization for other heavy flavor cross section measurements



ψ(2S) Production





$$R_{\psi(2S)} = \frac{\mathrm{Br}(\psi(2S)\to\ell^+\ell^-)\cdot\sigma_{\psi(2S)}}{\mathrm{Br}(J/\psi\to\ell^+\ell^-)\cdot\sigma_{J/\psi}} = \frac{N_{\psi(2S)}}{N_{J/\psi}}\cdot\frac{\varepsilon_{J/\psi}}{\varepsilon_{\psi(2S)}}$$

Invariant mass fits

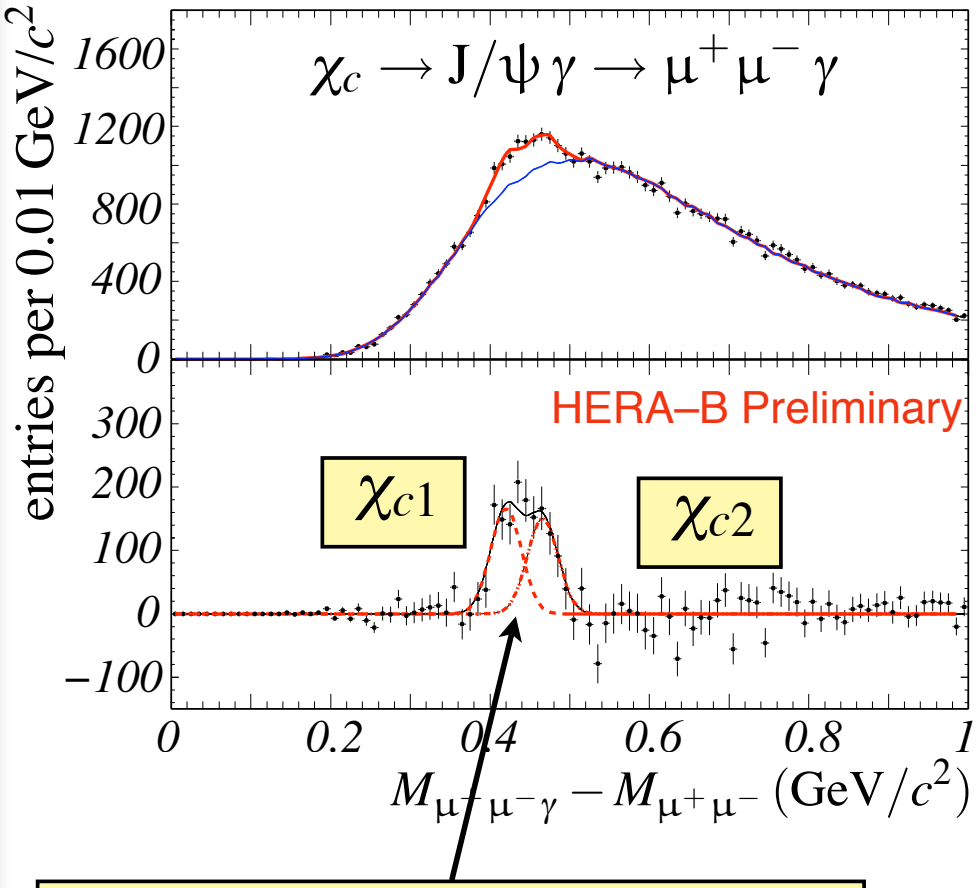
MC simulation

- Measure ψ(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 $E_T > 0.4$ 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, $\sigma_{pA} = N_A / (\mathscr{L}_A \cdot \varepsilon_A)$

$$\alpha = \frac{1}{\log(A_W/A_C)} \log\left(\frac{N_W}{N_C} \cdot \frac{\mathscr{L}_C}{\mathscr{L}_W} \cdot \frac{\varepsilon_C}{\varepsilon_W}\right)$$

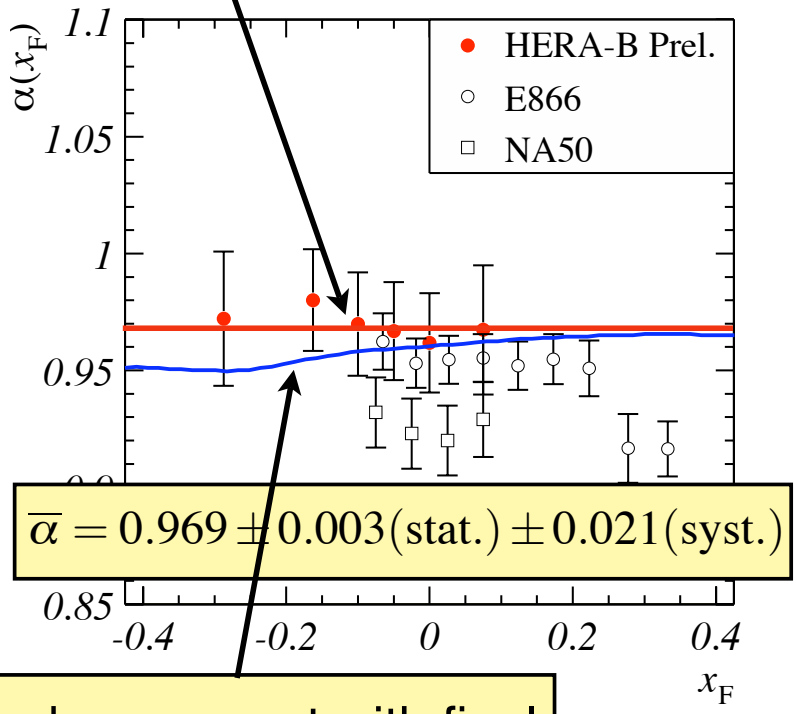
I. Ratio of J/ψ yields: fits to invariant mass spectra

II. Ratio of luminosities: count primary vertices per wire

III. Ratio of efficiencies: detailed detector/trigger simulation

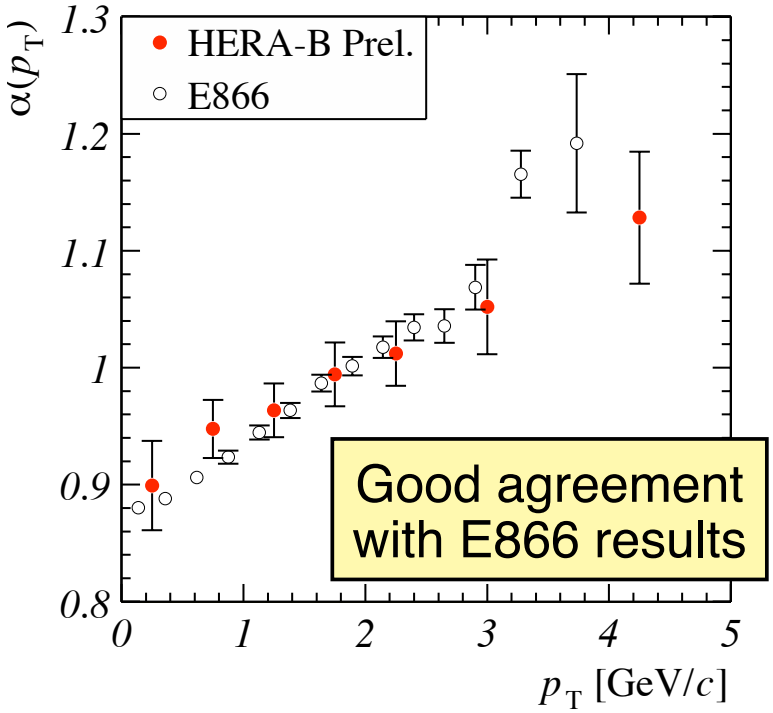
Nuclear Effects: Results

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



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

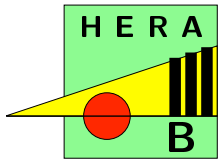
Dimuon channel, full data-set
(to be combined with electron result)



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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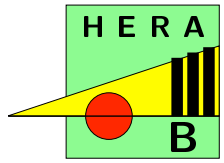
B Production Cross Section



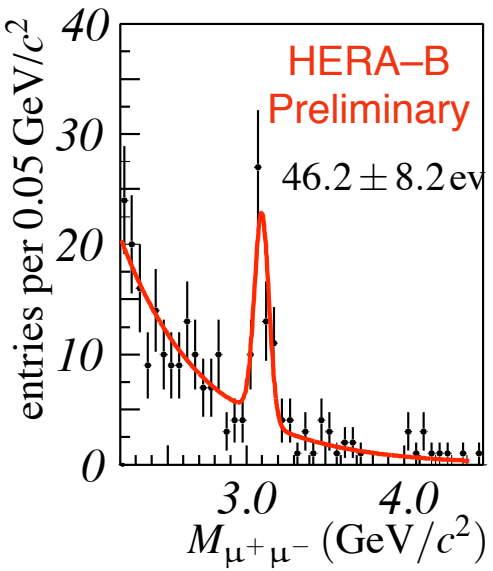
- Beauty production at fixed-target experiments close to kinematic threshold: large theoretical and experimental uncertainties
  - Experiments: low statistics, large systematic uncertainties
  - Theory: soft gluon resummation, b quark mass
- HERA–B: inclusive channel $pA \to b\bar{b} \to J/\psi X \to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

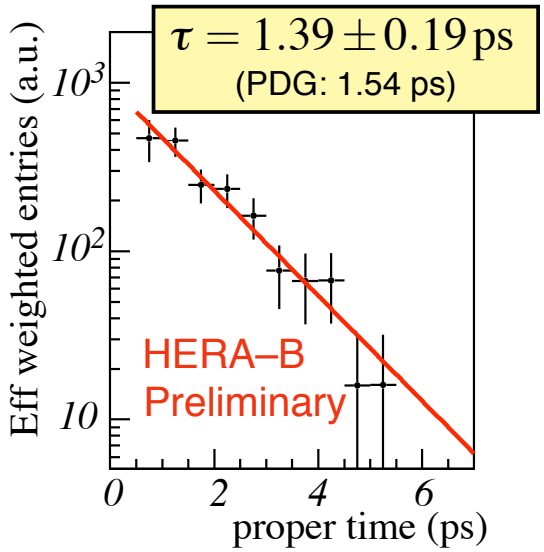
$$R_{b\bar{b}} = \frac{\Delta\sigma_{b\bar{b}}}{\Delta\sigma_{J/\psi}} = \varepsilon \cdot \frac{N_{b\bar{b}\to J/\psi X}}{N_{\text{prompt } J/\psi}}$$

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





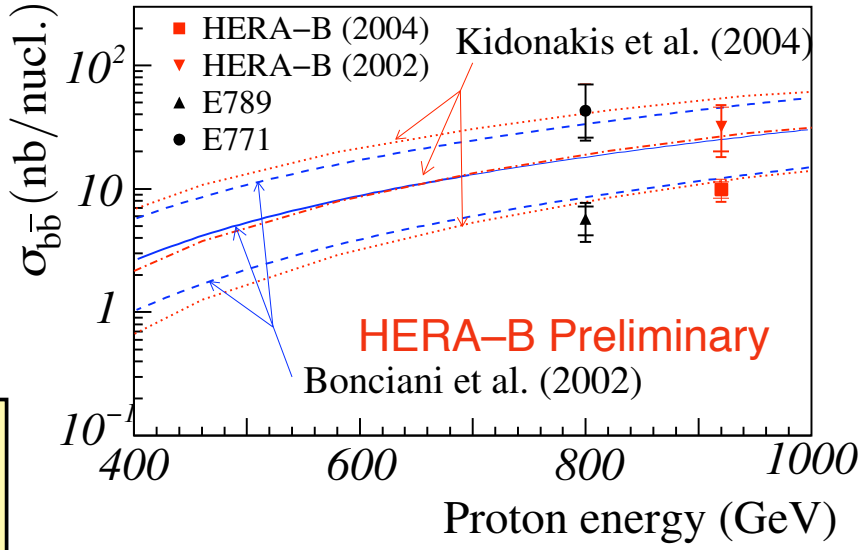
B Cross Section: Results

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

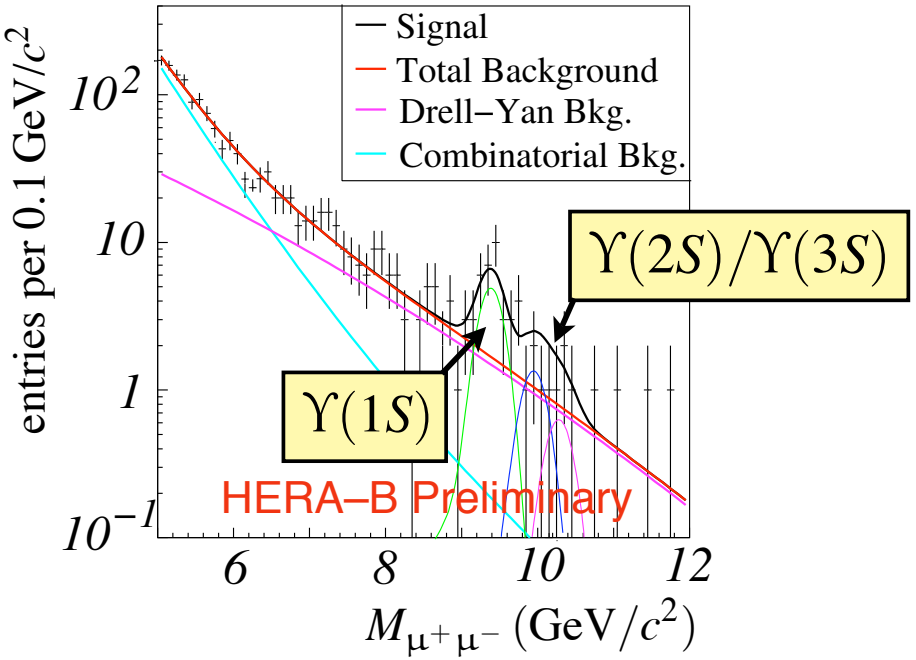
$$\frac{\Delta\sigma_{b\bar{b}}}{\Delta\sigma_{J/\psi}} = 0.033 \pm 0.005(\text{stat.}) \pm 0.004(\text{syst.})$$

- 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)

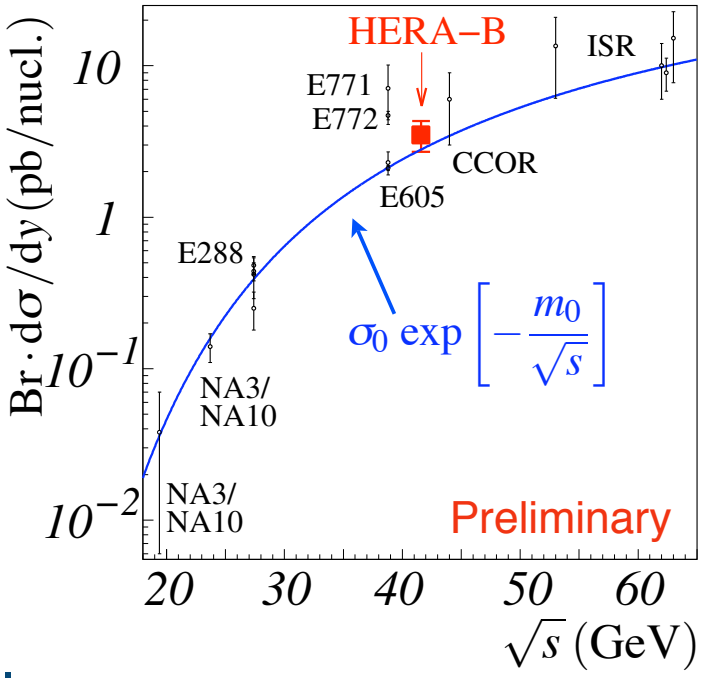
$$\sigma_{b\bar{b}} = 9.9 \pm 1.5(\text{stat.}) \pm 1.4(\text{syst.})\,\text{nb/nucl.}$$



Υ Production



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



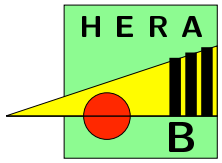
Measure relative to $\sigma_{J/\psi} = 352\,\mathrm{nb/nucl.}$

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

→ Data compatible with no nuclear effects

→ Drell-Yan: consistent with previous expts.

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 $x_F < -0.1$
  - ψ(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