Open Beauty and Quarkonia production in 920 GeV Proton–Nucleus Collisions

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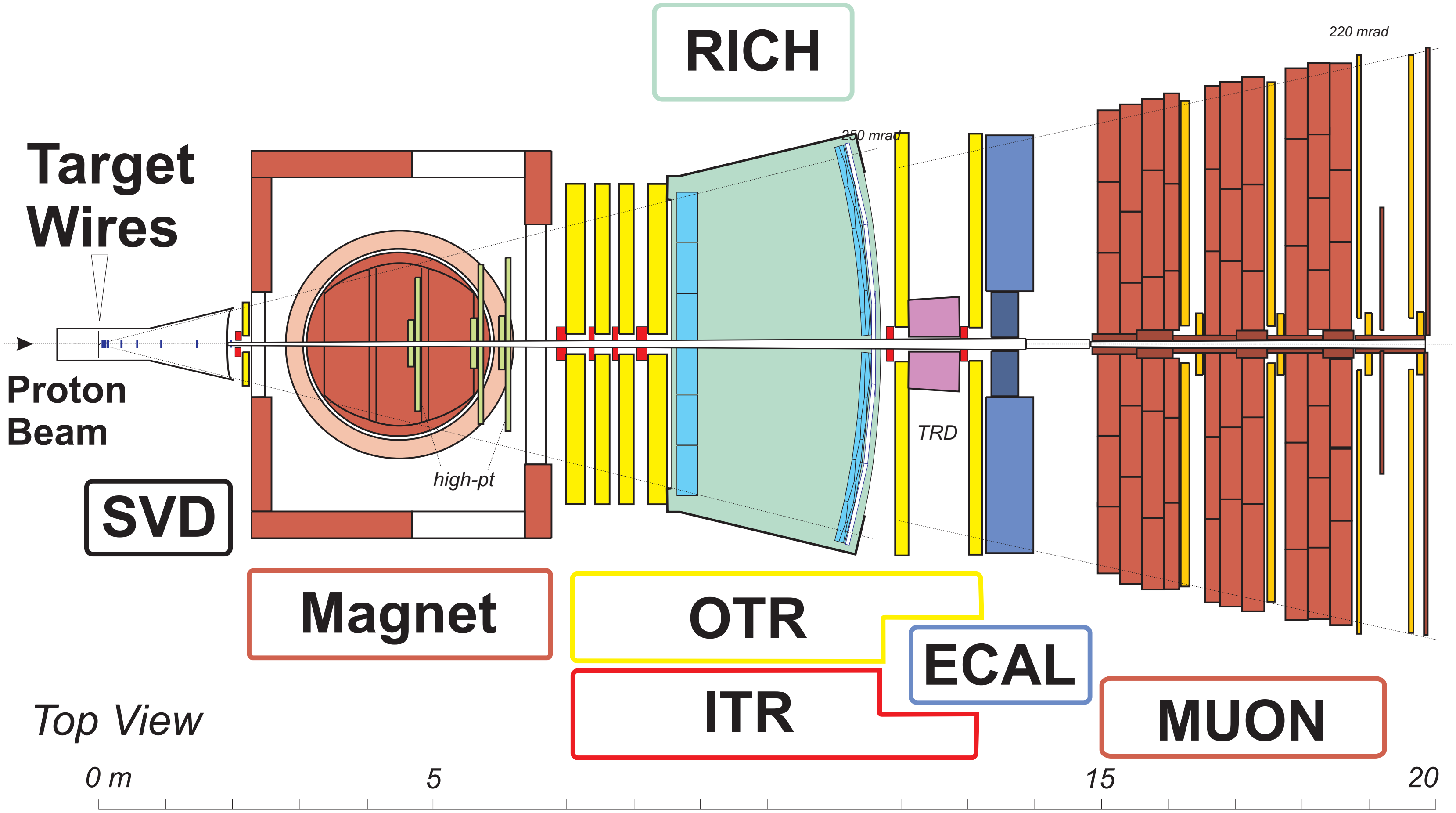
Contents

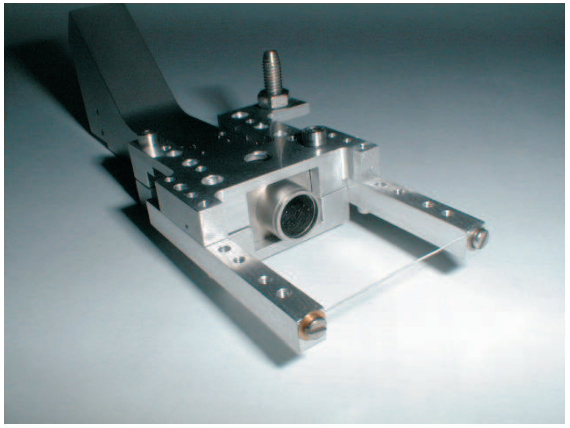
- The HERA–B detector and trigger
- Physics program
- Upsilon production:
  - $pA \rightarrow \Upsilon + X$, $\Upsilon \rightarrow e^+e^-/\mu^+\mu^-$
- Open beauty production:
  - Measurement of the $b\bar{b}$ production cross section
- Outlook

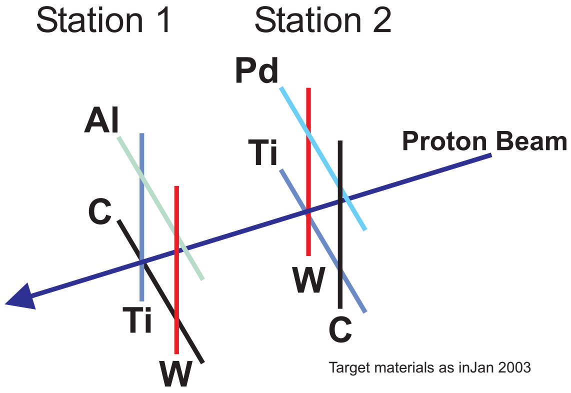
The HERA–B Detector

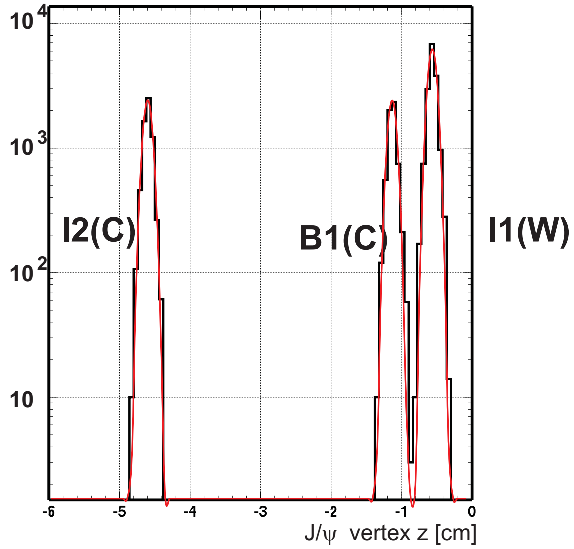
A fixed target spectrometer at the HERA proton beam
$\sqrt{s} = 41.6$ GeV



Target







- Different targets can be used simultaneously.
  A–dependence measurements $\Rightarrow$ control of systematic errors.
- Events from different wires can be separated easily.

J/ψ–Trigger

HERA-B Detector: on average ½ interaction per proton bunch

5 MHz

Pretriggers: ECAL cluster or MUON hit coincidence

3 MHz

FLT: track based hardware trigger (track finding behind magnet)

20 kHz

SLT (PC farm): track finding, SVD, vertexing

100 Hz

4LT (PC farm): online reconstruction

Trigger on 2 leptons from J/ψ decay

Main trigger setup in 2002/3:
2 pretrigger seeds
+ $1\ FLT$ track
+ $2\ SLT$ tracks

Year	$J/\psi\ h^{-1}$
2000	25-30
2002/3	1000-1500

HERA–B Physics Program

Di-lepton trigger:

- **A.** **Charmonium** production: $J/\psi,\ \psi',\ \chi_c$
- **B.** $\boldsymbol{A}$**-dependence** of charmonia production
- **C.** $\boldsymbol{b\bar{b}}$ production cross section

See talk U. Husemann on A and B

In addition

220 million **minimum bias** events:

strangeness production, open charm, ...

J/ψ production cross section

Data Sets with Di-Lepton Triggers

2000: short physics run during HERA-B commissioning: runs with 1 and 2 target wires, mainly carbon and titanium,

$\approx 8600\ J/\psi$'s

2002/3: 3 months of data taking:

runs with 1 and 2 target wires,

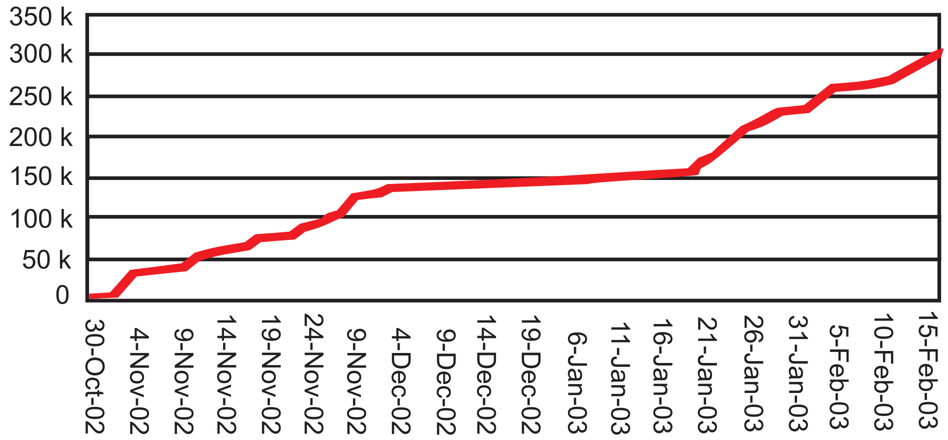
C, Ti and W targets,

$\sim 150 \cdot 10^6$ triggered events

mainly carbon and tungsten,

$\approx 300000\ J/\psi \rightarrow l^+ l^-$

J/ψ's collected in 2002/3

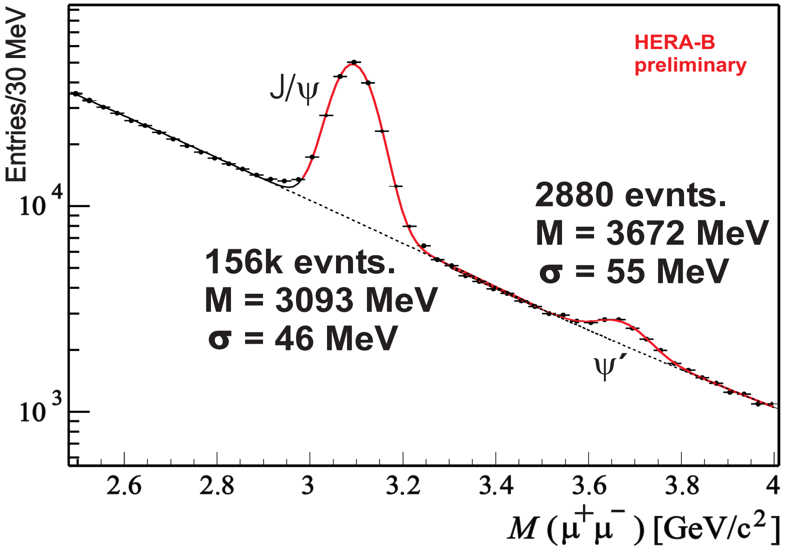


Many improvements for 2002/3

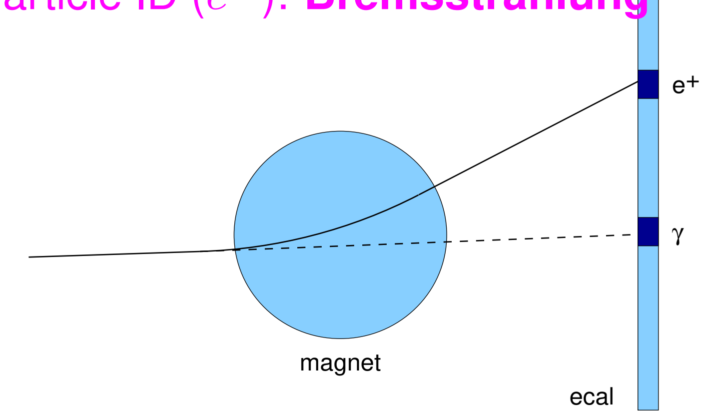
- Less material in magnet area
- ECAL: less noise, improved calibration
- Improved tracking efficiency, trigger, ...

Invariant Mass of Lepton Pairs in 2002/3

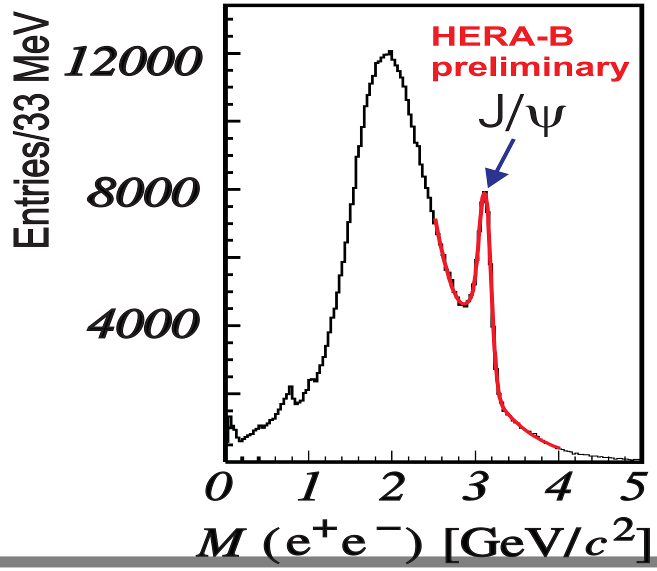
Muon



Particle ID ($e^{\pm}$): **Bremsstrahlung**

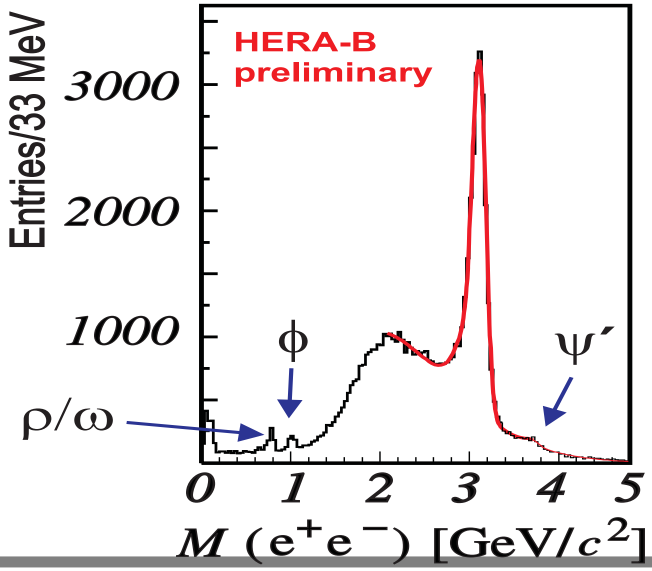


Electrons



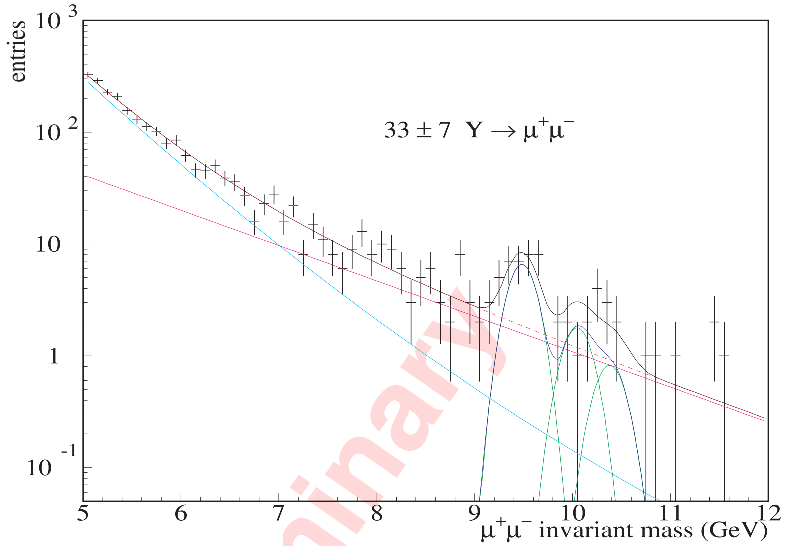
1 brems-strahlung γ

$\Longrightarrow$

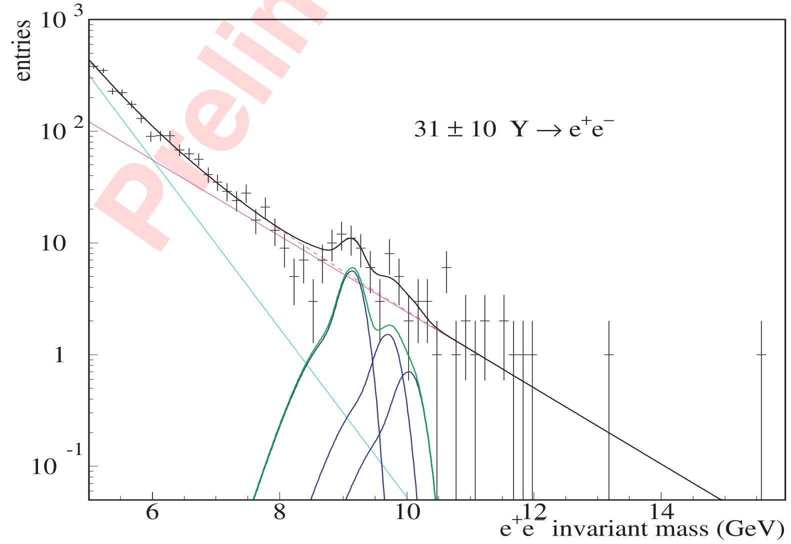


Υ production cross section

Muon



Electrons



relative measurement with respect to J/ψ

massresolution: 140 MeV $\leq \sigma_M \leq 160$ MeV

$\Upsilon(1S)/\Upsilon(2S)/\Upsilon(3S)$ relative production fixed on **E605**

signal: Υ shape taken from MC

background: shape from like sign lepton pairs, combinatiorial and Drell Yan

$$BR(\Upsilon \rightarrow l^+l^-) \times \left.\frac{d\sigma_\Upsilon}{dy}\right|_{y=0}(\sqrt{s})$$

$= (3.9 \pm 1.1)$ pb/nucl. (**Muons**)

$= (2.9 \pm 1.2)$ pb/nucl. (**Electrons**)

$= (\mathbf{3.4 \pm 0.8})$ pb/nucl. (**combined**)

Preliminary

Υ Hadroproduction

- Craigie parameterization modified for nuclear suppression:

$$BR(\Upsilon \to l^+l^-) \times \left.\frac{d\sigma_\Upsilon}{dy}\right|_{y=0}(\sqrt{s}) = \sigma_0 \cdot e^{-\frac{m_0}{\sqrt{s}}} \cdot A^{\alpha-1}$$

where $\sigma_0 = 144 \pm 28$ pb/nucl. and $m_0 = 161 \pm 6$ GeV

- Data compatible with no nuclear suppression:

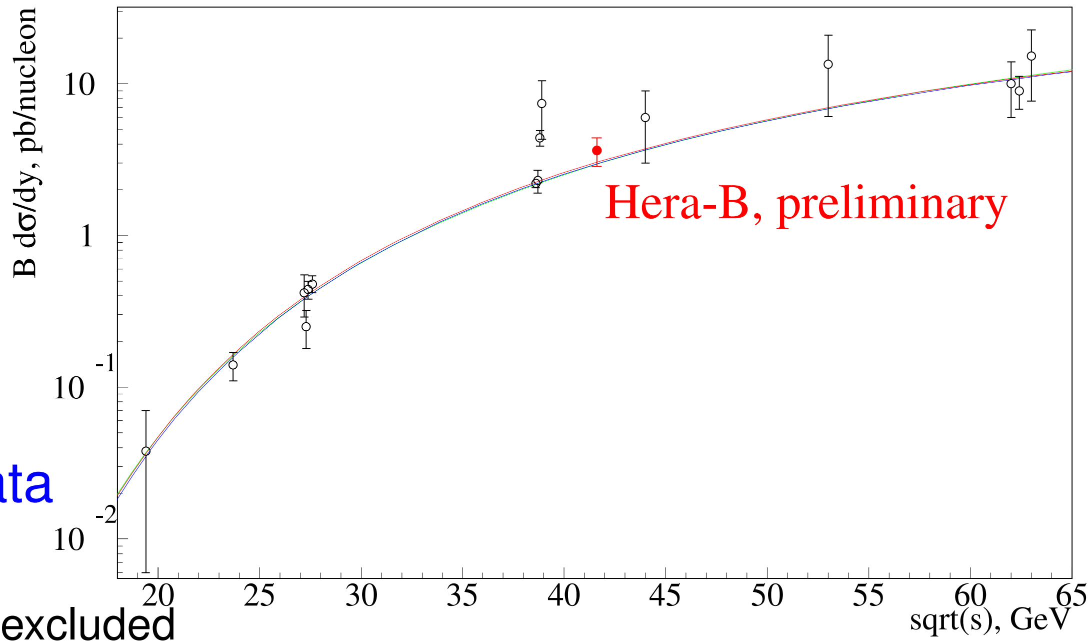
$\alpha = 0.99 \pm 0.05$

Targets used:

$50\ \%$ C$(A = 12)$

$50\ \%$ W$(A = 184)$

$\Rightarrow$ good fits to all exp. data



high value at $\sqrt{s} = 38$ GeV excluded

The HERA–B $\sigma(b\bar{b})$ Measurement

HERA–B can measure the $b\bar{b}$ cross section simultaneously in

$$b \to J/\psi X \to \mu^+\mu^- X \text{ and } b \to J/\psi X \to e^+e^- X$$

previous measurements:

Experiment	Proton Momentum	Target	$\sigma b\bar{b}$
E789	800 GeV/c	Au	$5.7 \pm 1.5 \pm 1.3$ nb/nucleon
E771	800 GeV/c	Si	$43^{+27}_{-17} \pm 7$ nb/nucleon
HERA-B 2000	920 GeV/c	C+Ti	$32^{+14}_{-12}(stat) \pm 8(sys)$ nb/nucleon

J/ψ acceptance region for HERA–B: $x_F \in [-0.35, 0.15]$

$$x_F = \frac{p_L^{cms}}{(p_L^{cms})_{max}}$$

Cross Section Formula

$\Rightarrow$ to minimize systematic errors and to remove luminosity measurement dependence:

$\sigma(b\bar{b})$ measured relative to prompt J/ψ cross section (n_P):

$$\boldsymbol{\Delta\sigma_{b\bar{b}} = \Delta\sigma_r \cdot \frac{n_B}{n_P} \cdot \frac{1}{\epsilon_R \cdot \epsilon_B^{\Delta z} \cdot BR(b\bar{b} \to J/\psi x)}}$$

- n_B/n_P: observed b and prompt J/ψ events
- ϵ_R: relative efficiency ($\epsilon_R = \epsilon_B^{J/\psi}/\epsilon_P^{tot}$, $\epsilon_B^{tot} = \epsilon_B^{J/\psi} \cdot \epsilon_B^{\Delta z}$)
  B– to prompt J/ψ–efficiency ratio (trigger + reco + selection)
- $BR(b\bar{b} \to J/\psi) = (2.32 \pm 0.20)$ %: branching ratio (LEP)
- $\Delta\sigma_r$: reference (prompt J/ψ) cross section in HERA–B acceptance
- $\Delta\sigma_{b\bar{b}}$: measured cross section in HERA–B acceptance

Reference cross section (prompt J/ψ)

Exp.	Target	E_p–Beam	$\sigma(J/\psi)$	α
E789	Au	800 GeV	$442 \pm 2 \pm 88$ nb/nuc.	0.9 ± 0.02
E771	Si	800 GeV	$375 \pm 4 \pm 30$ nb/nuc.	0.92 ± 0.008

using $\alpha = 0.955 \pm 0.005$ (**E866**) and scaling to HERA–B energies:

$$\sigma(pN \to J/\psi) = (357 \pm 8 \pm 27) \text{ nb/nuc.}$$

in our acceptance we see $f_P = (77 \pm 1)\ \%$ of the prompt J/ψ and $f_B = (90.6 \pm 0.5)\ \%$ of the $b\bar{b}$ events

Nuclear dependence A_P^α: $\alpha = 0.955 \pm 0.005$ for prompt J/ψ

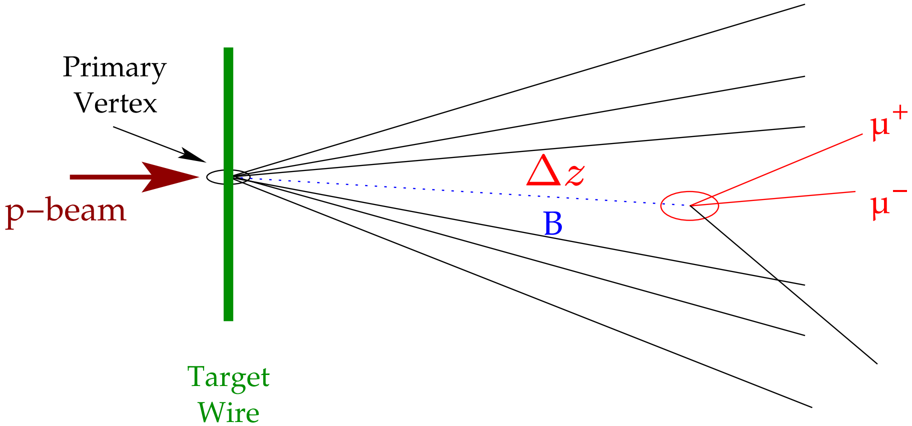
Reference prompt J/ψ cross section(E789 + E771):

$$\Delta\sigma_r = f_P \cdot \sigma(pN \to J/\psi) \cdot A_P^\alpha$$

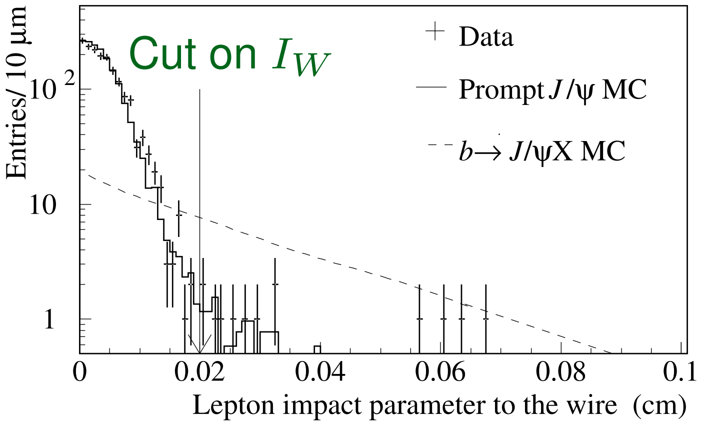
Detached Vertex Selection

Identify b–hadrons by their decay length using the decay chain

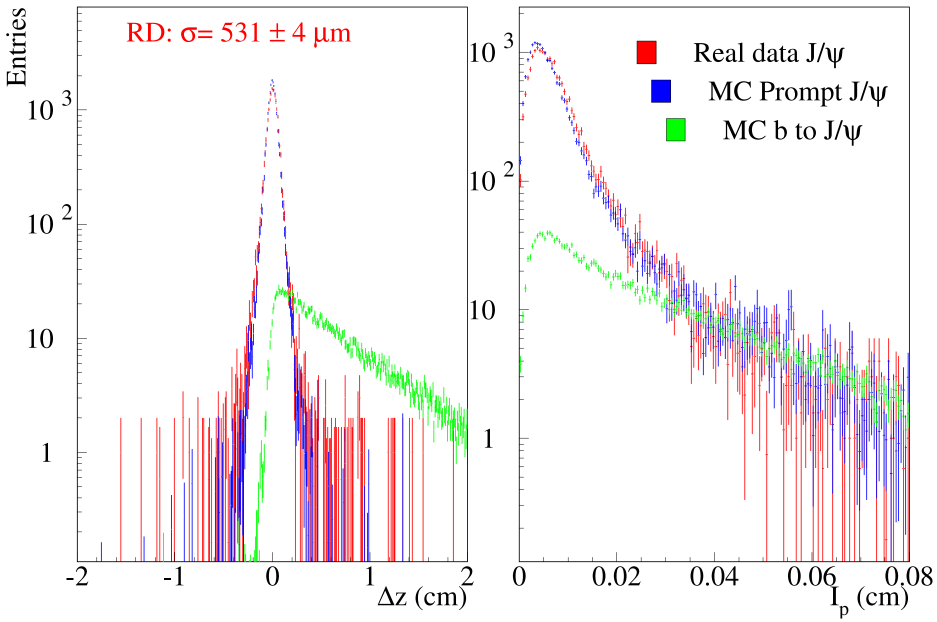
$$pN \to b\bar{b}X \to J/\psi XY \to l^+l^-XY$$



Impact parameter I_W



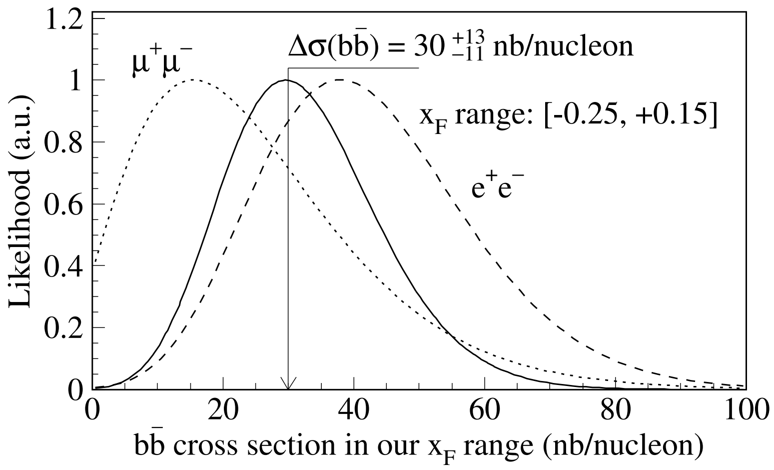
average decay length
$(DL = z_{J/\psi} - z_{wire} = \Delta z)$
of B–mesons at HERA–B:



$$DL \approx 7 \text{ mm} \gg \sigma_{\Delta z} \approx 0.5 \text{ mm}$$

The 2000 $\sigma(b\bar{b})$ Measurement

simultaneous fit to e^+e^- and $\mu^+\mu^-$ Data samples



e–channel:

$n_B = 8.6^{+3.9}_{-3.2}$, $n_P = 5710 \pm 380$

μ–channel:

$n_B = 1.9^{+2.2}_{-1.5}$, $n_P = 2880 \pm 60$

Target: $77\ \%$ C ($A = 12$) and $23\ \%$ Ti ($A = 48$)

Reference: $\sigma_r = 357 \pm 28$ nb/nuc.

Results in the x_F acceptance region of HERA–B

e–channel: $\Delta\sigma(b\bar{b}) = 38^{+18}_{-15}$ nb/nuc.

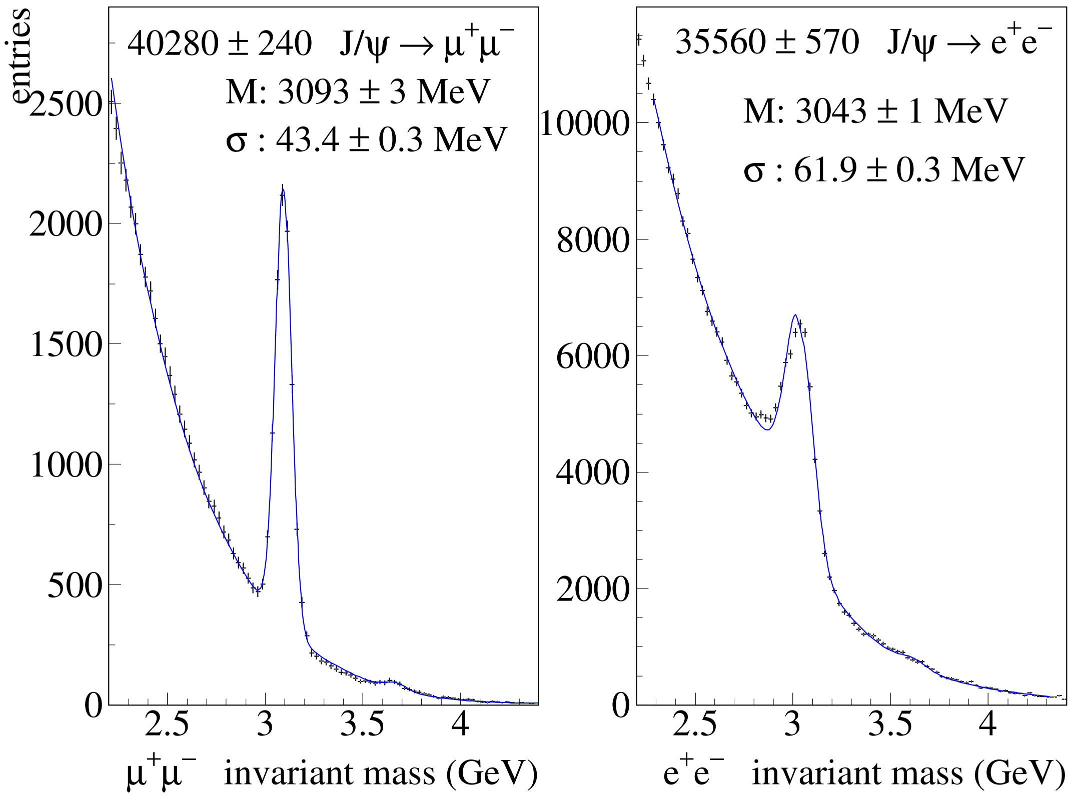
μ–channel: $\Delta\sigma(b\bar{b}) = 16^{+18}_{-12}$ nb/nuc.

$$\Delta\sigma(b\bar{b}) = 30^{+13}_{-11} \text{ nb/nucleon}$$

$$\boldsymbol{\sigma(b\bar{b}) = 32^{+15}_{-12} \pm 8_{sys}} \text{ nb/nucleon}$$ [**Eur.Phys.J.C26(2003)345**]

Status of analysis of 2002/3 data

Prompt J/ψ μ/e–signals on $\backsim$ **30 %** of full statistics



μ–channel:

$\boldsymbol{n_P^\mu = 40280 \pm 240}$

e–channel:

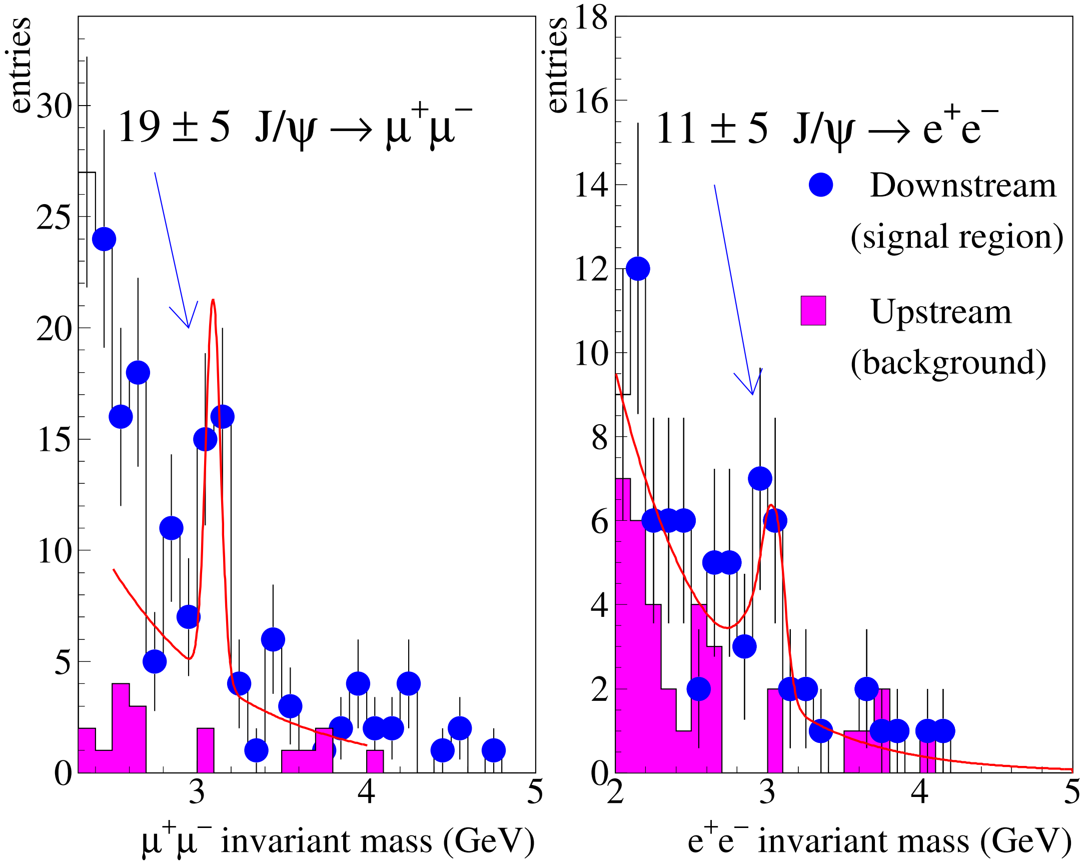
$\boldsymbol{n_P^\mu = 35560 \pm 570}$

PID: $\boldsymbol{\mu}$: likelihood from Muon detector and RICH $\boldsymbol{e}$: E/p

$\boldsymbol{J/\psi}$ **acceptance:** $-0.35 < x_F < 0.15$

Detached J/ψ Signal in 2002

Detached J/ψ μ/e–signals on $\backsim$ **30 %** of full statistics



unbinned maximum likelihood fit:

$$n_B^\mu = 19 \pm 5$$

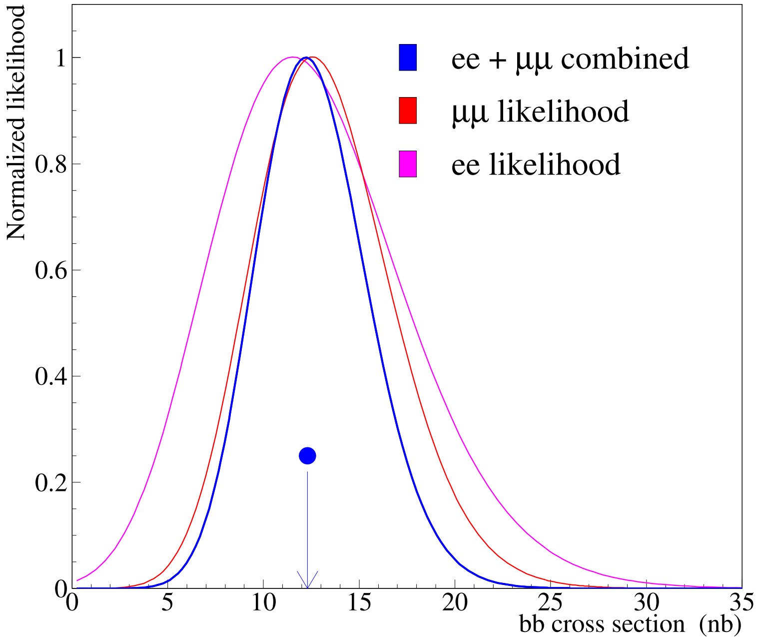
$$n_B^e = 11 \pm 5$$

cut optimized with blind analysis technique:
signal from MC and BG from data

$\epsilon_{\Delta z} \approx 30 - 40$ %

Preliminary Result $\sigma(b\bar{b})$ 2002

$$\Delta\sigma_{b\bar{b}} = \Delta\sigma_r \cdot \frac{n_B}{n_P} \cdot \frac{1}{\epsilon_R \cdot \epsilon_B^{\Delta z} \cdot BR(b\bar{b} \to J/\psi x)} \qquad \sigma_{b\bar{b}} = \Delta\sigma_{b\bar{b}}/f_B$$



$BR(b\bar{b} \to J/\psi X) = (2.32 \pm 0.02)$ %

$\Delta\sigma_r^C = (245 \pm 6 \pm 19)$ nb/nuc.

$f_B = (90.6 \pm 0.5)$ %

μ–channel: $\sigma(b\bar{b}) = 12.7\,^{+4.1}_{-3.6}$ nb/nucl.

e–channel: $\sigma(b\bar{b}) = 11.5\,^{+5.3}_{-4.5}$ nb/nucl.

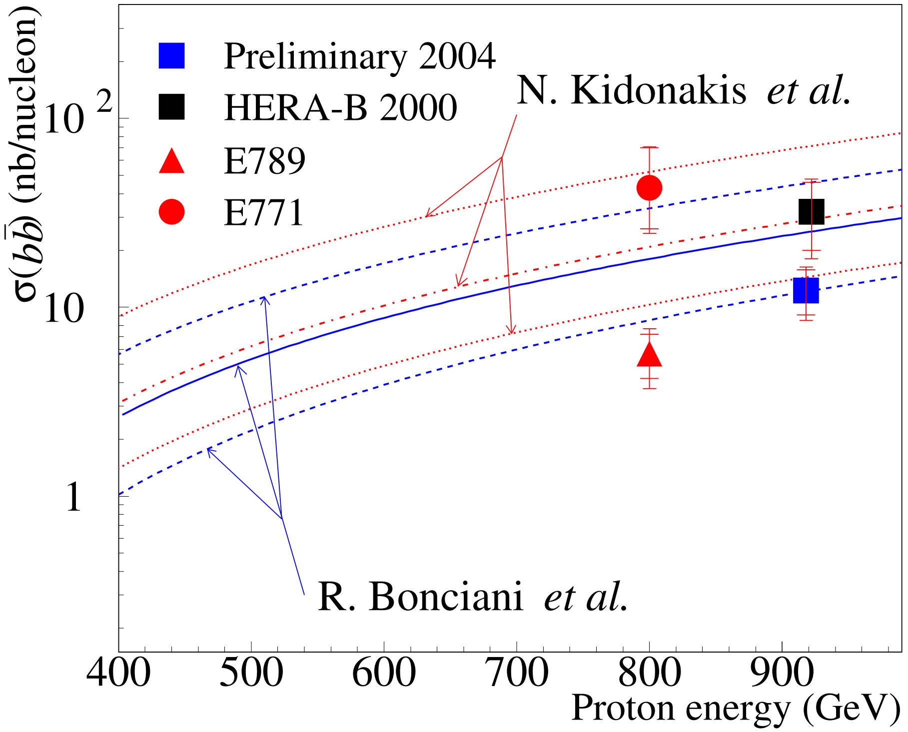
min. syst. error ≈ 20 %

preliminary combined result: $\sigma(b\bar{b}) = 12.3\,^{+3.5}_{-3.2}$ nb/nucl.

analysis on reduced sample (≈ 30 %):

single wire run I2 (C) 2002 and double wire I1I2 (W,C) 2002

Comparison to QCD Models



measurement with data of 2000 shows good agreement with QCD calculation beyond NLO

measurement with new data (2002/3) is $1.5\ \sigma$ lower than 2000 measurement

Analysis is still going on

- N. Kidonakis et al, Phys.Rev.D64(2001)114001.
  NLO + NNLL: $15 < \sigma(b\bar{b}) < 70$ nb/nucl.
- R. Bonciani et al, Nucl.Phys.B529(1998)24.
  NLO+NLL: $12 < \sigma(b\bar{b}) < 45$ nb/nucl.
  corrected for the last MRST pdf: A.D. Martin et al., Phys.Lett.B531(2002)216.

Systematic Uncertainties

for the analysis using the data of 2000

expectations for the data of 2002/3 (full statistics

source	channel	err.2000 $[\%]$	err.2002/3 $[\%]$
reference J/ψ cross section (σ_r)	e, μ	$11\ \%$	$11\ \%$
prompt J/ψ MC production model ($\epsilon_P^{J/\psi}$)	e, μ	$2.5\ \%$	$2.5\ \%$
b production and decay model (ϵ_B^{tot})	e, μ	$8\ \%$	$8\ \%$
trigger simulation (ϵ_R)	e, μ	$5\ \%$	$5\ \%$
A dependence ignored in $\epsilon_R \cdot \epsilon_B^{\Delta z}$	e, μ	$1.7\ \%$	$1.7\ \%$
b lifetime error ($\epsilon_B^{\Delta z}$)	e, μ	$< 1\ \%$	$< 1\ \%$
prompt J/ψ counting (n_P)	e	$5\ \%$	$1\ \%$
$J/\psi \to e^+e^-\gamma$ channel	e	$1\ \%$	$1\ \%$
background shape	e / μ	$14\ \%$ / $20\ \%$	$5\ \%$ / $7\ \%$
background fluctuations	e / μ	$11\ \%$ / $23\ \%$	$4\ \%$ / $8\ \%$
total contribution	$\boldsymbol{e}$ / $\boldsymbol{\mu}$	**$24\ \%$ / $33\ \%$**	**$16\ \%$ / $18\ \%$**

Outlook

- HERA-B has stopped data taking
- expected number of detached events: $\backsim$ 50 in both channels
- N_b one order of magnitude higher than in previous fixed target experiments
- input on b-Quark mass and on QCD calculations
- exclusive b–decay search ($B^{\pm} \to J/\psi K^{\pm}$, $B^0 \to J/\psi K^{\pm}\pi^{\mp}$, $B^0 \to J/\psi K_s$) ongoing
- search for double semileptonic decays ($b\bar{b} \to \mu\mu X$, $B \to \mu\nu X$): analysis in progress

Summary

- Hera-B has acquired large statistics of charmonium events in 2002-2003

$\sigma_{b\bar{b}}$ measurement:

- new measurement of $\sigma(b\bar{b})$ with part of the statistics, compatible with measurement of 2000
- clear improvement of the measurement in statistical errors and systematic uncertainties for full statistics expected
- additional measurement of $\sigma_{b\bar{b}}$ using exclusive and double semileptonic b decays
- preliminary results for cross sections:
  - $\boldsymbol{BR(\Upsilon \to l^+l^-) \times \sigma_\Upsilon = (3.4 \pm 0.8)}$ pb/nucl.
  - $\boldsymbol{\sigma(b\bar{b}) = 12.3\ ^{+3.5}_{-3.2}}$ nb/nucl.