Hidden and Open Beauty Production in 920 GeV Proton–Nucleus Collisions

QCD and high Energy Hadronic Interactions – 39th Rencontres de Moriond 2004

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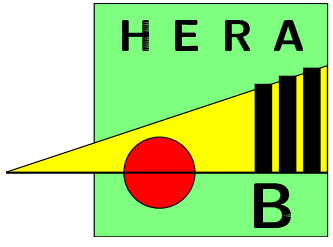


bmb+f - Förderschwerpunkt
HERA - B
Großgeräte der physikalischen Grundlagenforschung

Contents

- the HERA–B detector and trigger
- hidden beauty production:
  - $pA \to \Upsilon + X$, $\Upsilon \to e^+e^-/\mu^+\mu^-$
- open beauty production:
  - measurement of the $b\bar{b}$ production cross section
- outlook

HERA–B Physics Program

the HERA–B **ABC**

A. A**-dependence** of charmonia production

B. $b\bar{b}$ production cross section

C. **Charmonium** production: $J/\psi,\ \psi',\ \chi_c$

in addition

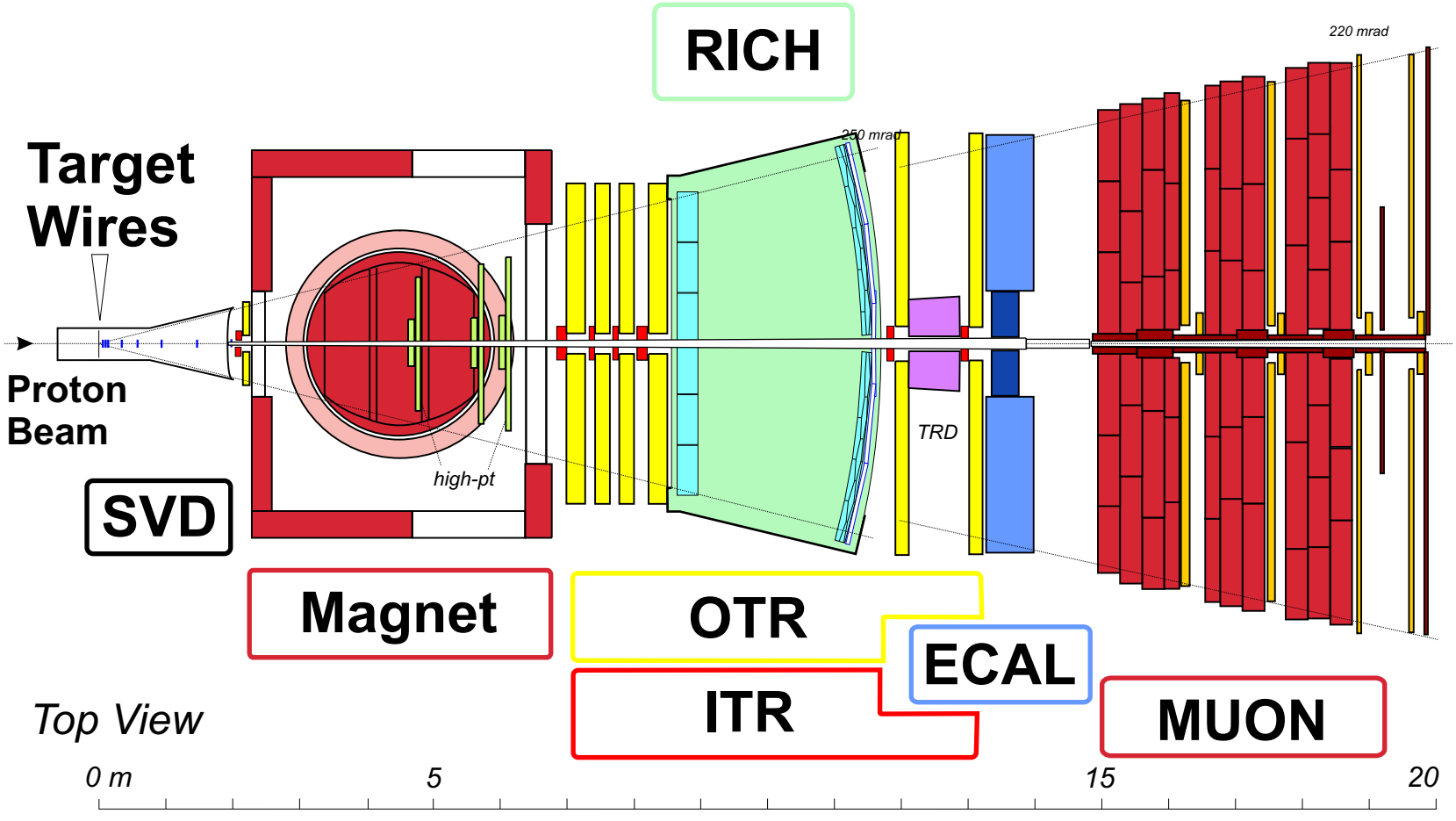
220 million **minimum bias** events:

strangeness production, open charm, ...

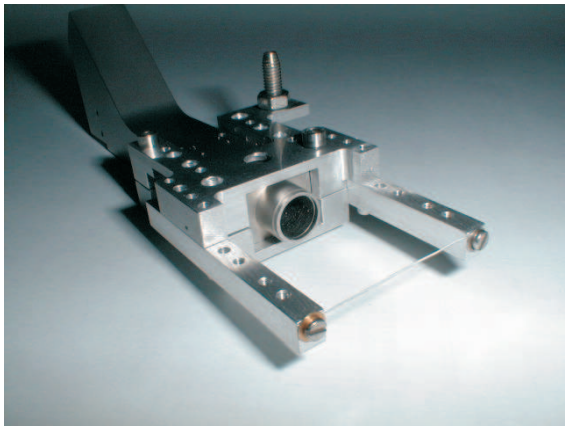
J/ψ production cross section

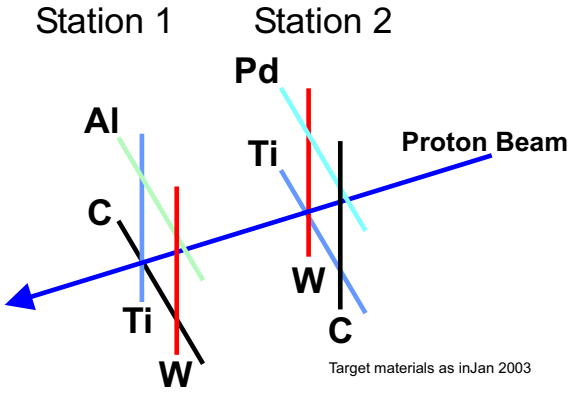
The HERA–B Detector

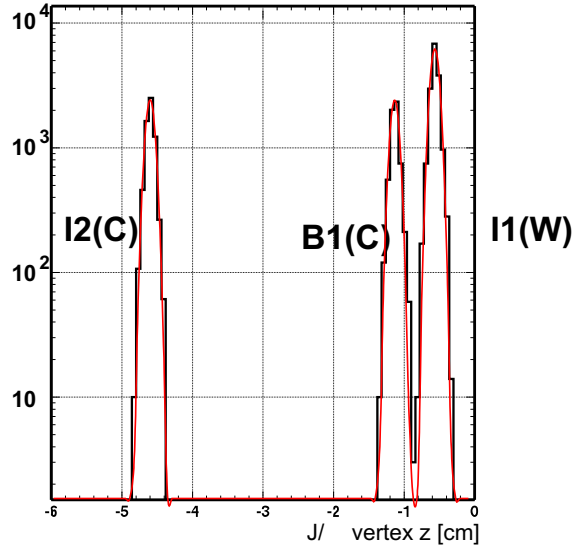
a fixed target spectrometer at the HERA proton beam $\sqrt{s} = 41.6$ GeV:



Target

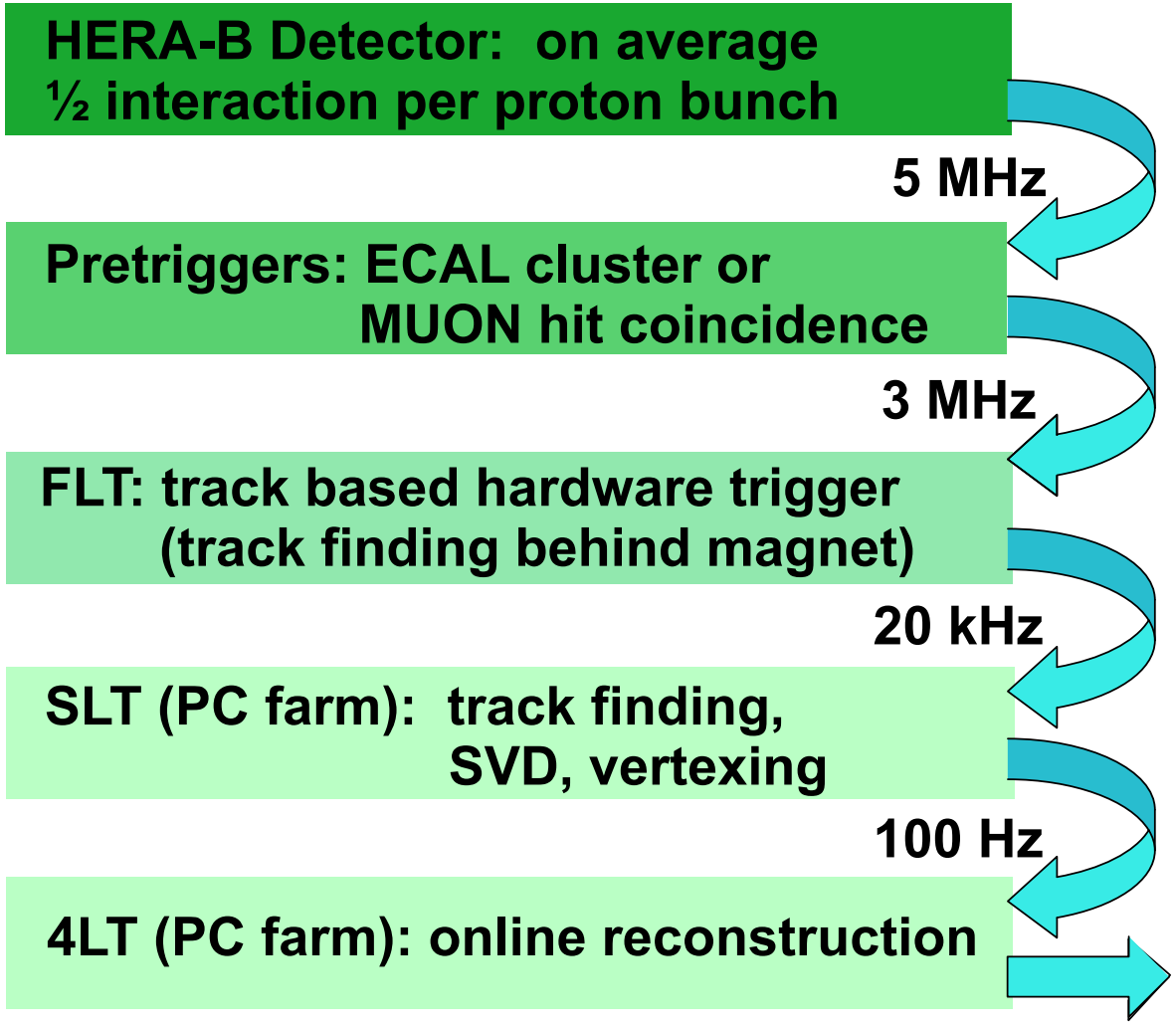






- different targets can be used simultaneously,
  A–dependence measurements $\Rightarrow$ control of systematic errors
- events from different wires can be separated easily

Dilepton–Trigger



main trigger setup in 2002/3:

$(1\ FLT$ track) + $(2\ SLT$ tracks with PreTrigger seeds)

so-called $1FLT/2SLT^*$ mode

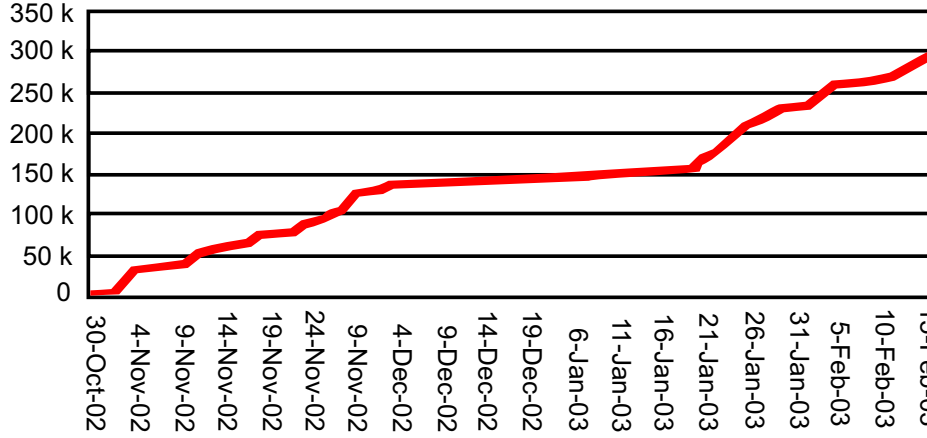
Year	$J/\psi\ h^{-1}$
2000	25-30
2002/3	1000-1500

Data Sets with Dilepton 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, Pd and W targets,
$\sim 150 \cdot 10^6$ triggered events
mainly carbon and tungsten,
$\approx 300000\ J/\psi \to l^+l^-$

J/ψ's collected in 2002/3

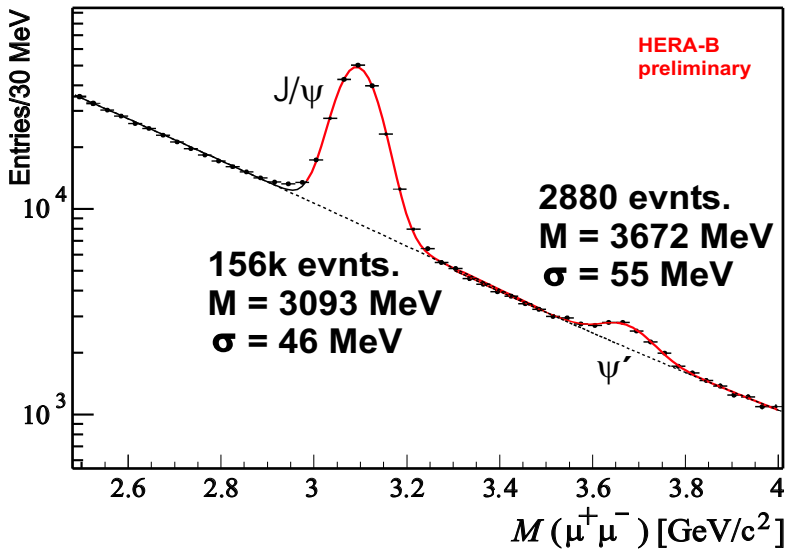


many improvements for 2002/3

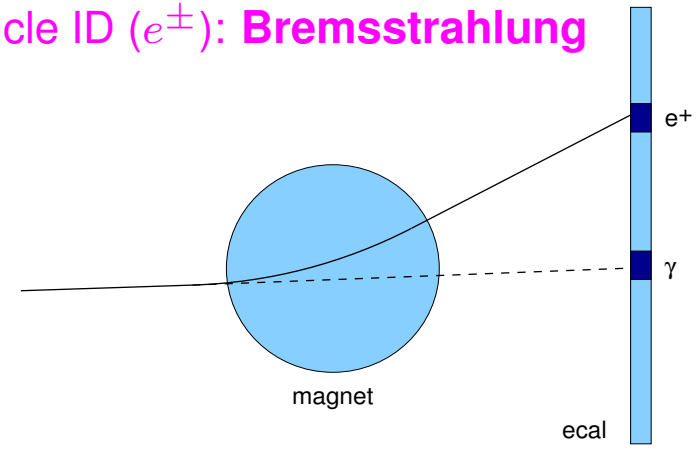
- less material in magnet area
- ECAL: less noise, improved calibration
- improved tracking efficiency, trigger, ...

Invariant Mass of Lepton Pairs in 2002/3

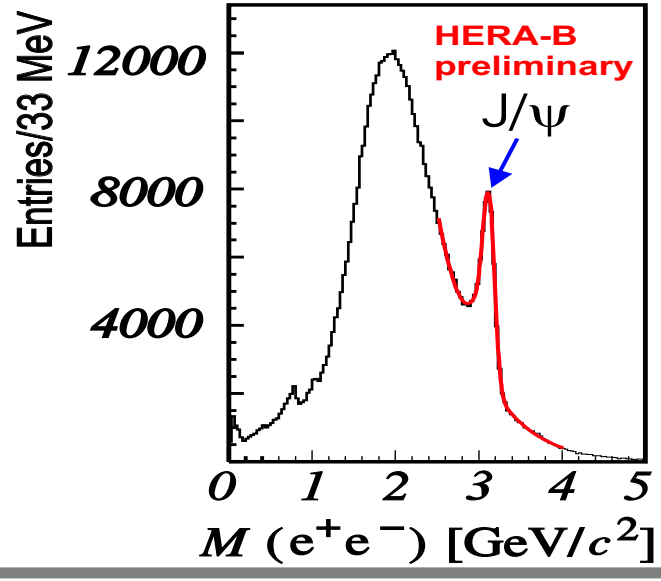
muons



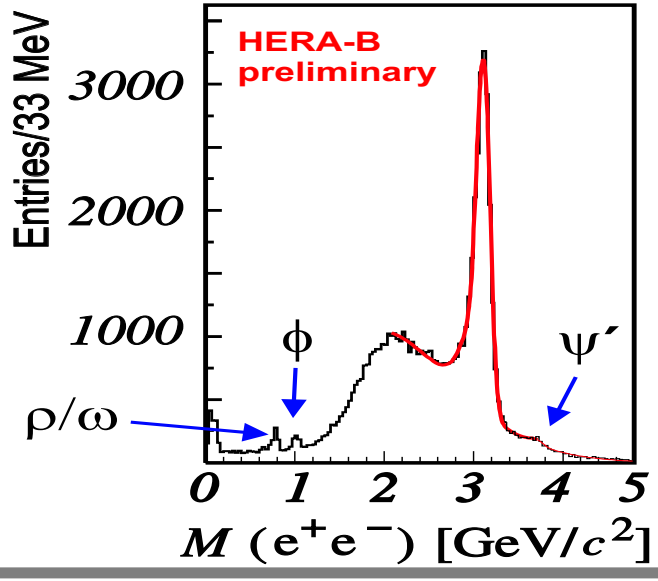
Particle ID ($e^{\pm}$): **Bremsstrahlung**



electrons

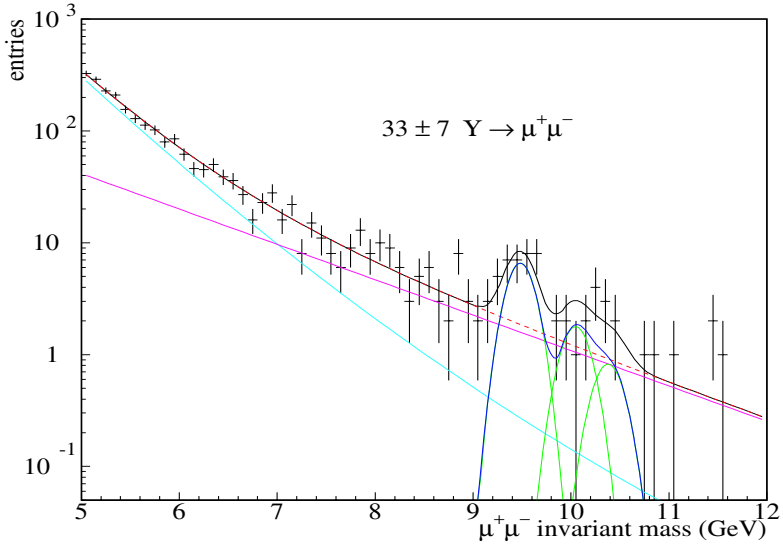


1 brems-
strahlung γ
$\Longrightarrow$

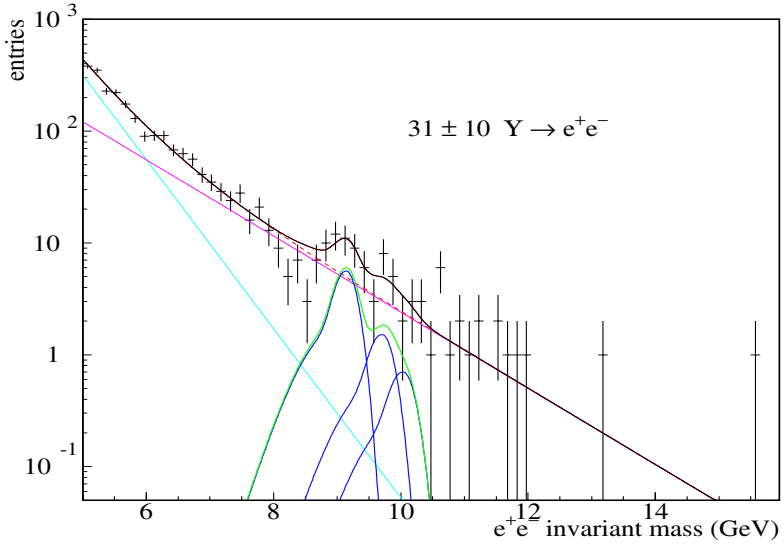


Υ Production Cross Section

muons



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, combinatorial and Drell Yan

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

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

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

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

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:

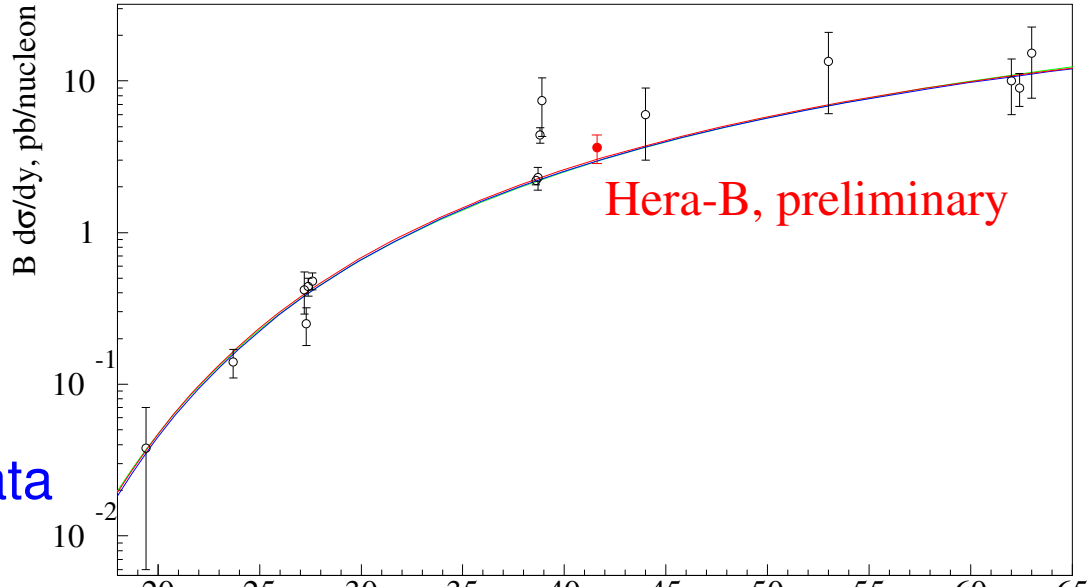
$\alpha = 0.99 \pm 0.05$

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

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

common approach to e and μ:

- increase statistics
- cross check the result

first measurement of $\sigma(b\bar{b})$ in a fixed–target experiment and in negative x_F region:

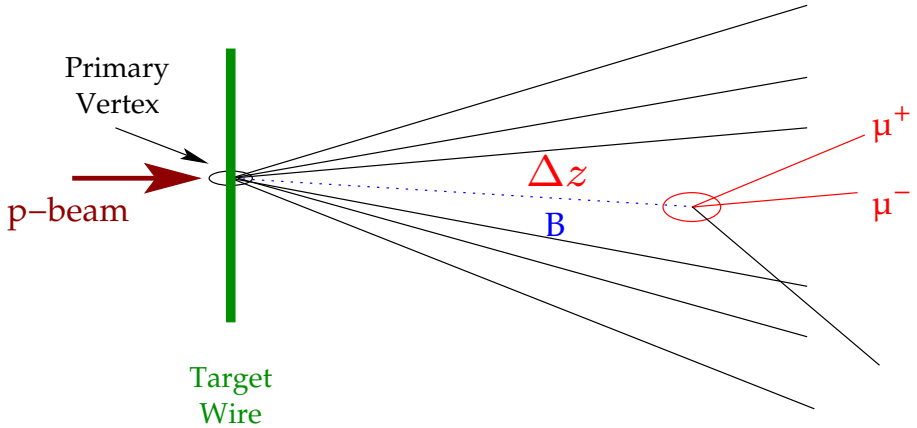
J/ψ acceptance region for HERA–B: $x_F \in [-0.35, 0.15]$

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

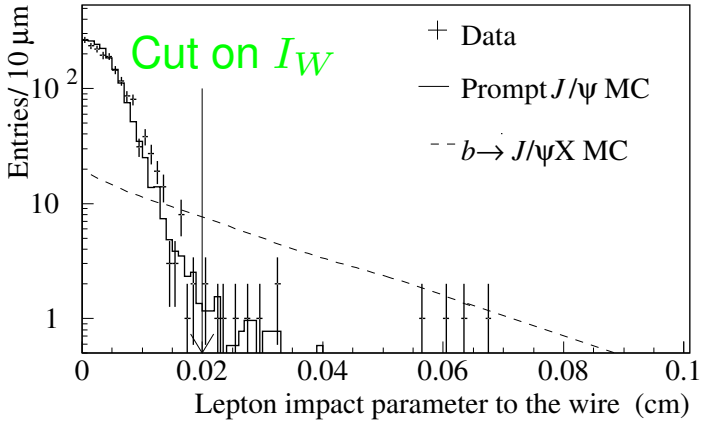
Detached Vertex Selection

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

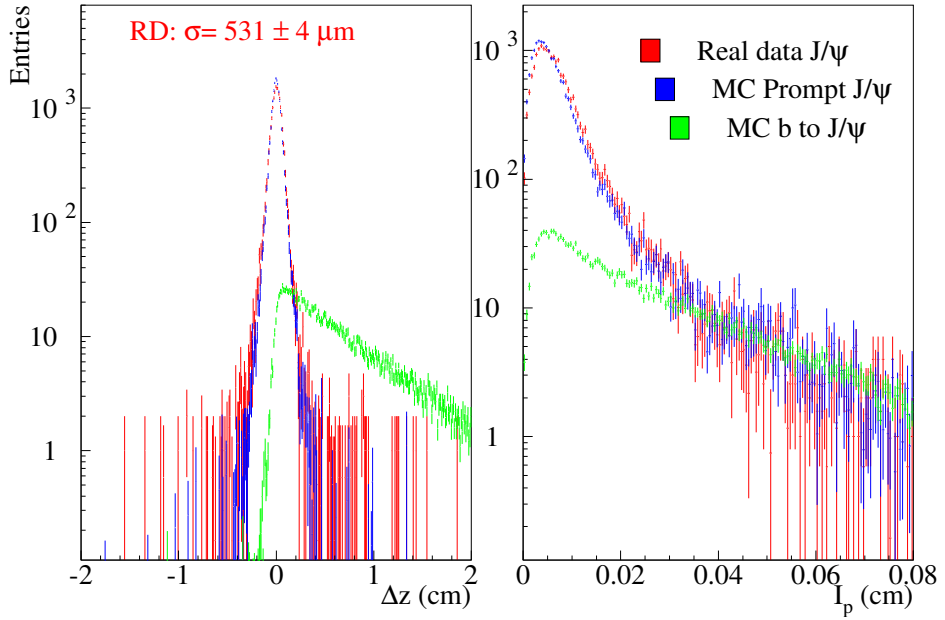
$$pN \rightarrow b\bar{b}X \rightarrow J/\psi XY \rightarrow l^+l^-XY$$



Impact parameter I_W



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



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

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):

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

- 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/nucl.	0.9 ± 0.02
E771	Si	800 GeV	$375 \pm 4 \pm 30$ nb/nucl.	0.92 ± 0.008

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

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

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

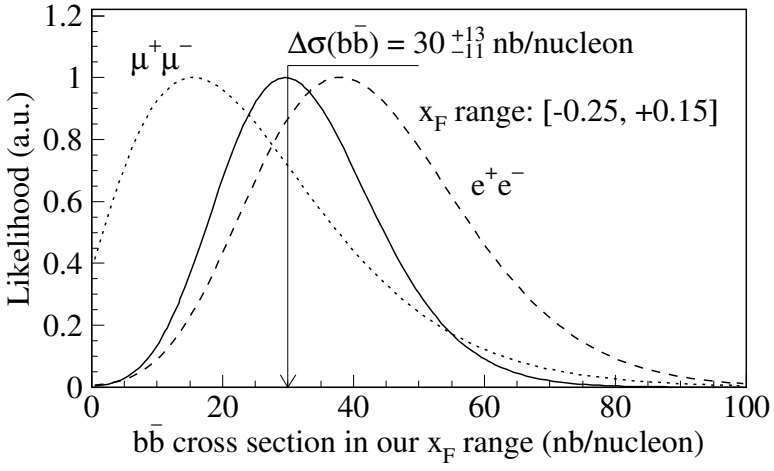
nuclear dependence A_P^α: $\alpha = 0.955 \pm 0.005$ for prompt J/ψ

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

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

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/nucl.

results in the x_F acceptance region of HERA–B

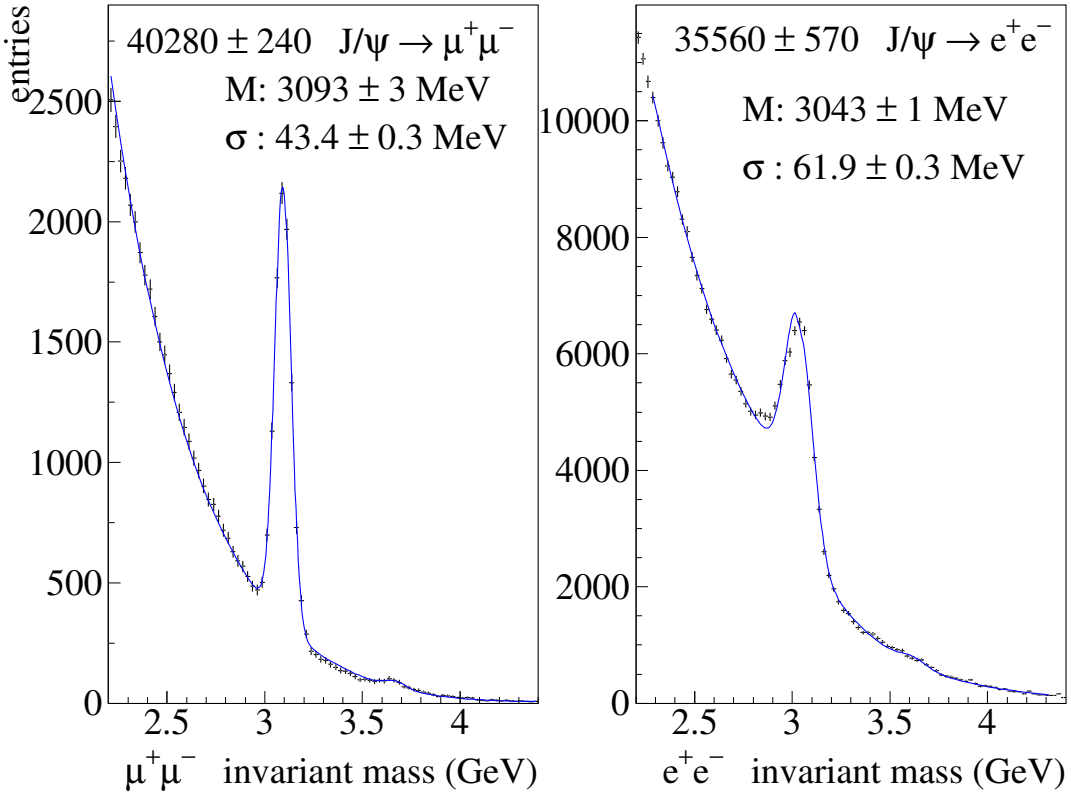
e–channel: $\Delta\sigma(b\bar{b}) = 38^{+18}_{-15}$ nb/nucl. μ–channel: $\Delta\sigma(b\bar{b}) = 16^{+18}_{-12}$ nb/nucl.

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

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

Status of Analysis of 2002/3 Data

prompt J/ψ μ/e–signals on Carbon-target ($\approx$ **30 %** of full statistics)



μ–channel:

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

e–channel:

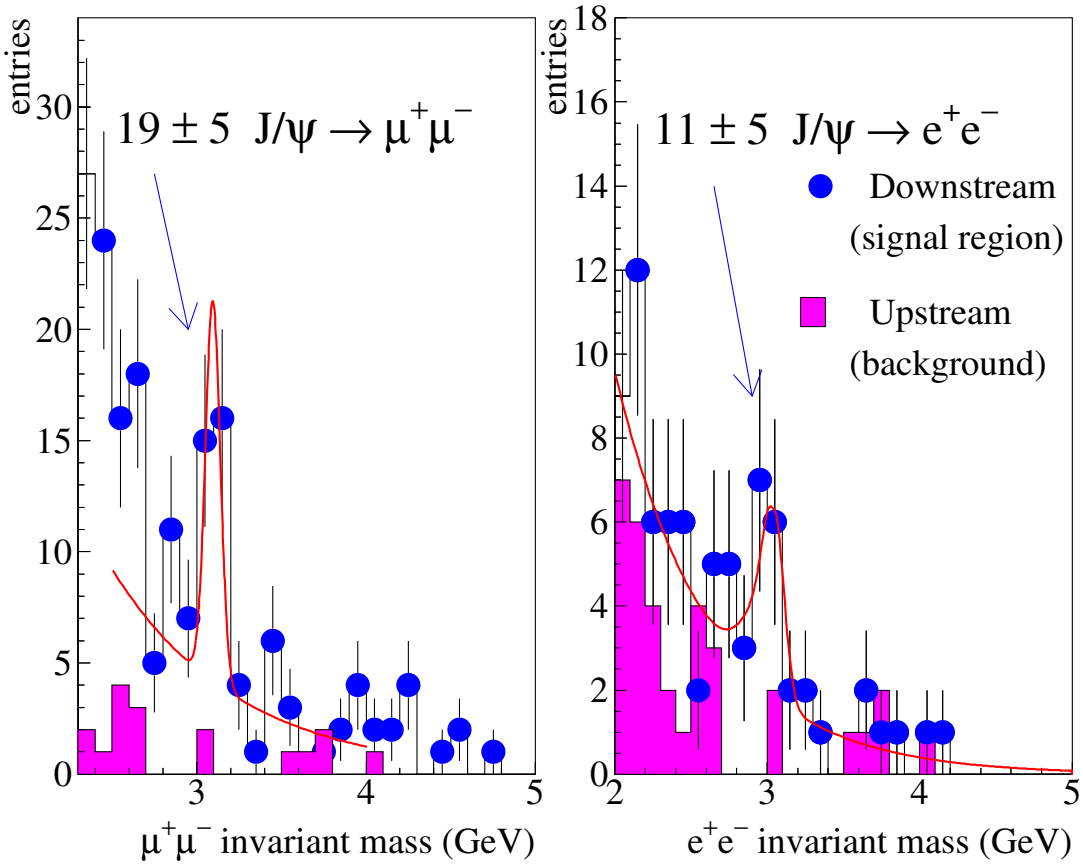
$$n_P^{e} = 35560 \pm 570$$

PID: μ: likelihood from μ–detector and RICH, e: $(E/p)^{+4.0\sigma}_{-1.8\sigma}$ cut

J/ψ acceptance: $-0.35 < x_F < 0.15$

Detached J/ψ Signal in 2002

detached J/ψ μ/e–signals on Carbon-Target (≈ 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

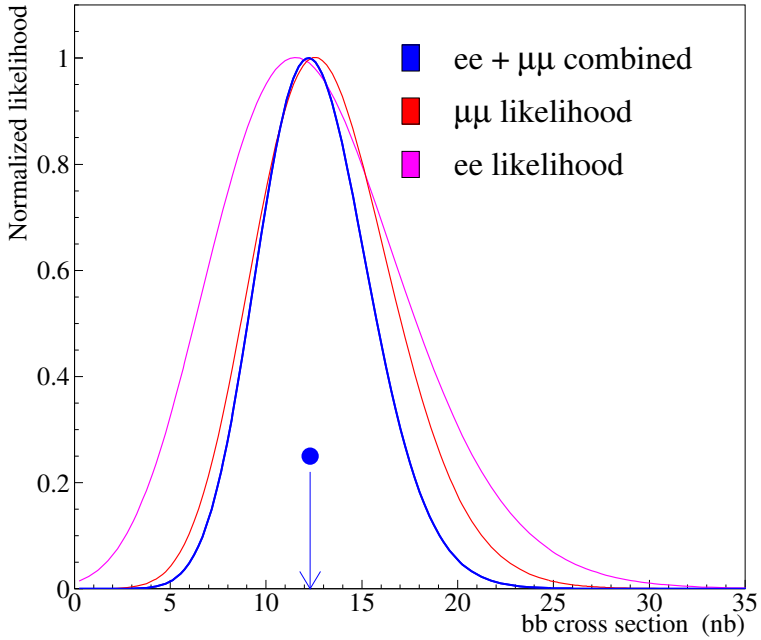
$\epsilon_{\Delta z} \approx 30 - 40$ %

decay length cut: $|\Delta z| > 0.2$ cm and $|\Delta z| > 7.5/8.5 \cdot \sigma_Z$

cut on impact parameter to primary vertex: $I_P > 160$ μm

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/nucl.

$f_B = (90.6 \pm 0.5)\ \%$

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

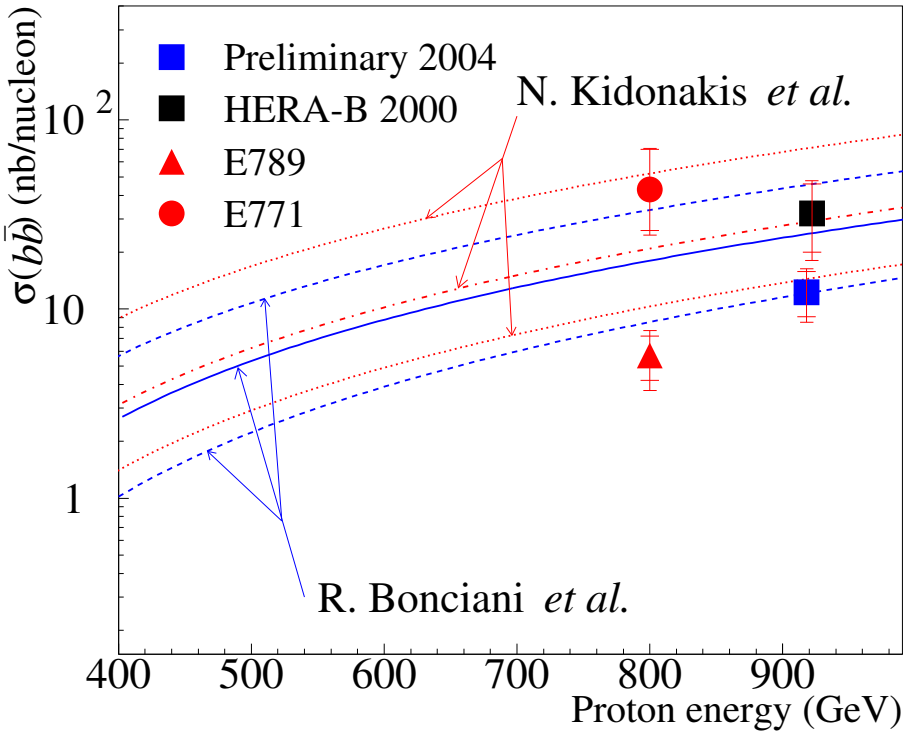
e–channel: $\sigma(b\bar{b}) = 11.5\ ^{+5.3}_{-4.5}$ nb/nucl.

min. syst. error $\approx 20\ \%$

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

analysis on reduced sample ($\approx 30\ \%$): single wire runs 2002 (I2, C)

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	e / μ	**24 % / 33 %**	**16 % / 18 %**

Outlook

- **HERA–B has stopped data taking**
- we expect ~ 50 detached J/ψ's in μ–channel and ~ 50 in e–channel
- 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 ($B^{\pm} \to J/\psi K^{\pm}$, $B^0 \to J/\psi K^{\pm}\pi^{\mp}$, $B^0 \to J/\psi K_s$) and search for double semileptonic decays ($b\bar{b} \to \mu\mu X$, $B \to \mu\nu X$): analysis in progress

Summary

- 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:
  - $\boldsymbol{\sigma(\Upsilon) = (3.4 \pm 0.8)}$ pb/nucl.
  - $\boldsymbol{\sigma(b\bar{b}) = (12.3\ ^{+3.5}_{-3.2})}$ nb/nucl.