Measurement of the $b\bar{b}$ Production Cross Section in Proton-Nucleus Collisions at Hera-B

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1. Motivations
2. The HERA-B spectrometer and trigger (Y2K)
3. The Measurement: $b \rightarrow J/\psi(l^+l^-) + X$
4. Comparison with Data & QCD Predictions
5. Conclusions

(hep-ex/0205106 + submit. EPJ C)

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Motivations for a $b\bar{b}$ cross section measurement at Hera-B

A test for QCD Predictions:

$12 \leq \sigma(b\bar{b}) \leq 70$ nb/nucl.
at 920 GeV/c (Hera-B)

→ **Recent improvements but still large uncertainties !**

Fixed Target Data:

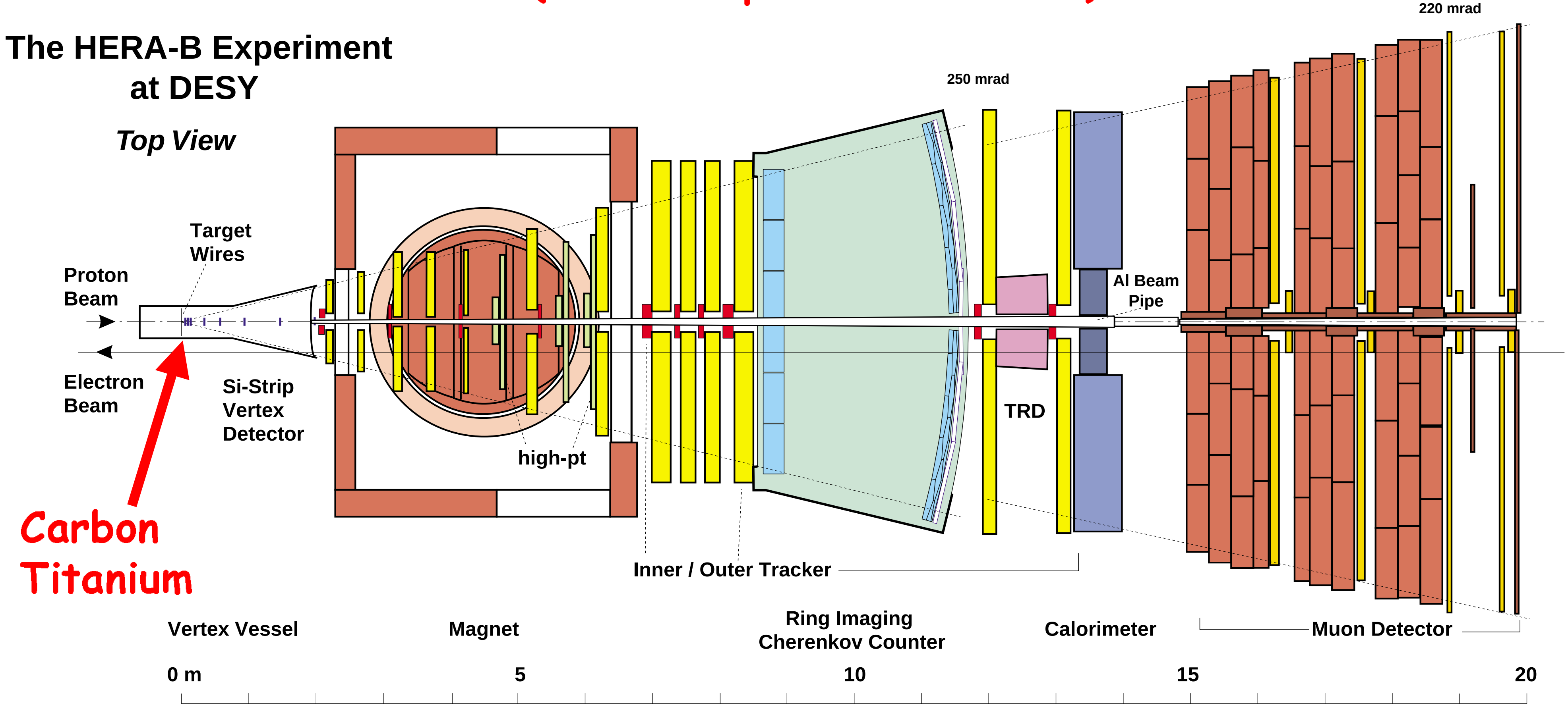
Exp	Targ	p Beam	$\sigma(b\bar{b})$ nb/nucleon	Channel
E789	Au	800 (GeV/c)	5.7 ±1.5 ±1.3	$b \rightarrow J/\psi(\mu^{\pm})$ X
E771	Si	800 (GeV/c)	$43 \,^{+27}_{-17} \pm 7$	$b\bar{b} \rightarrow (\mu^{+}+X)(\mu^{-}+X)$

→ Hera-B can extend the experimental panorama by covering both $b \rightarrow J/\psi(e^{\pm})$ and $b \rightarrow J/\psi(\mu^{\pm})$ & the non-exploited negative x_F region

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

The Hera-B Detector

(920 GeV p-N interactions)



Y2K J/ψ-coverage: $-0.25 < x_F < 0.15$ (now $-0.4 < x_F < 0.3$)

The Hera-B Di-lepton Trigger (Y2K)

Pretrigger (5 MHz)
E_t cut for e, hit coinc. for μ

Level I (~150 KHz)
2 leptons (ee, $\mu\mu$) requirement (no tracking !)

Level II (~12 KHz)
2 tracks in Main Tracker and Vertex Detector

(Farms of 240+100 PCs, ~20 Hz output)

9.0 10^5 di-e & 4.5 10^5 di-μ events

The measurement steps

1. **Select prompt J/ψ**

2. **Select b→J/ψ**

$$\Delta\sigma(b\bar{b}) = \sigma_r \cdot \frac{n_B}{n_P} \frac{1}{\varepsilon_R \cdot \varepsilon_B^{\Delta z} \cdot Br(b\bar{b} \to J/\psi\ X)}$$

Detached Vertex selection Efficiency

Relative detection Efficiency $(\frac{\varepsilon_B}{\varepsilon_P})$

3. **Normalize to σ(pN →J/ψX)**

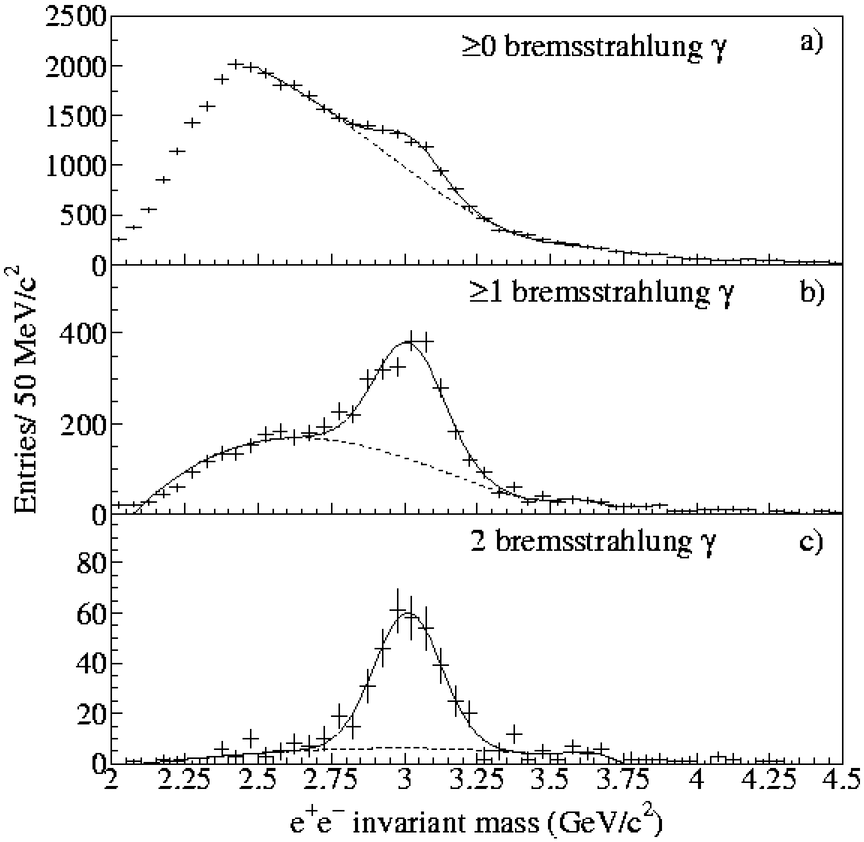
using E789/E771 ½ [-0.25 < x_F < 0.15]

⇒ **Minimize systematic errors & Avoid luminosity dependence**

Prompt J/ψ selection

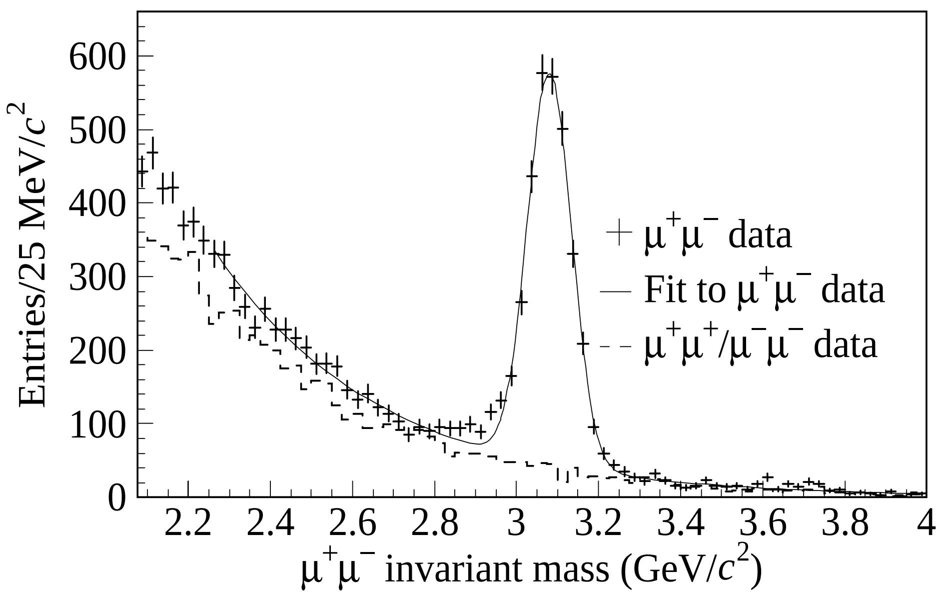
Reconstruction based on Trigger tracks + Vertex + Particle ID

Electron Channel:



n_P= 5710±380$_{st}$±280$_{sys}$

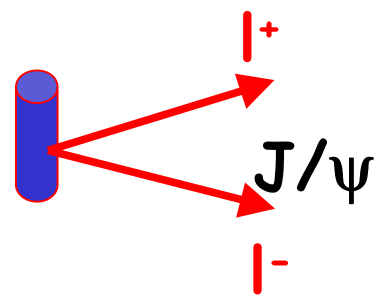
Muon Channel:



n_P= 2880±60

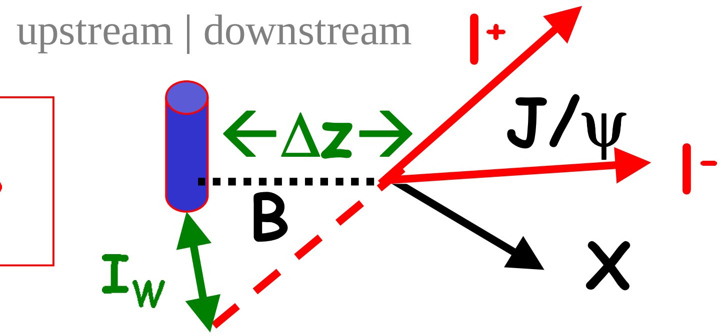
Isolating the b signal

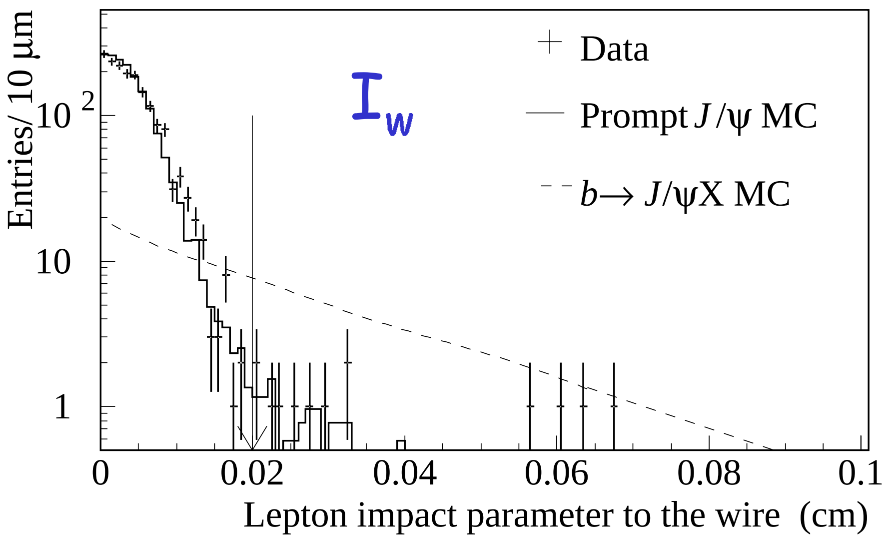
Total (prompt) J/ψ signal | **Detached $b \to J/\psi$ signal**

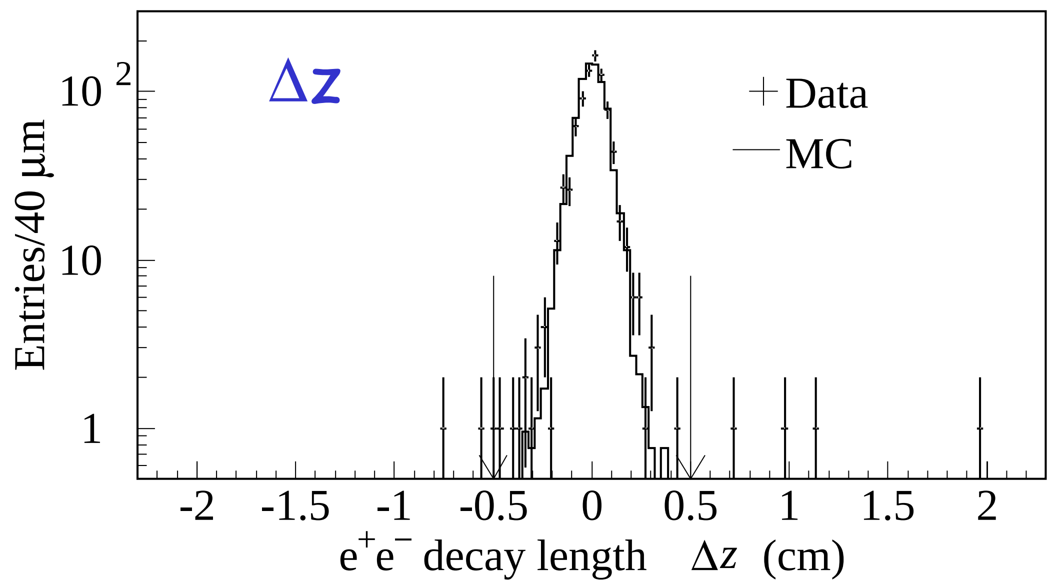


$\sigma(\Delta z) \ll \langle \gamma c \tau \rangle_B$

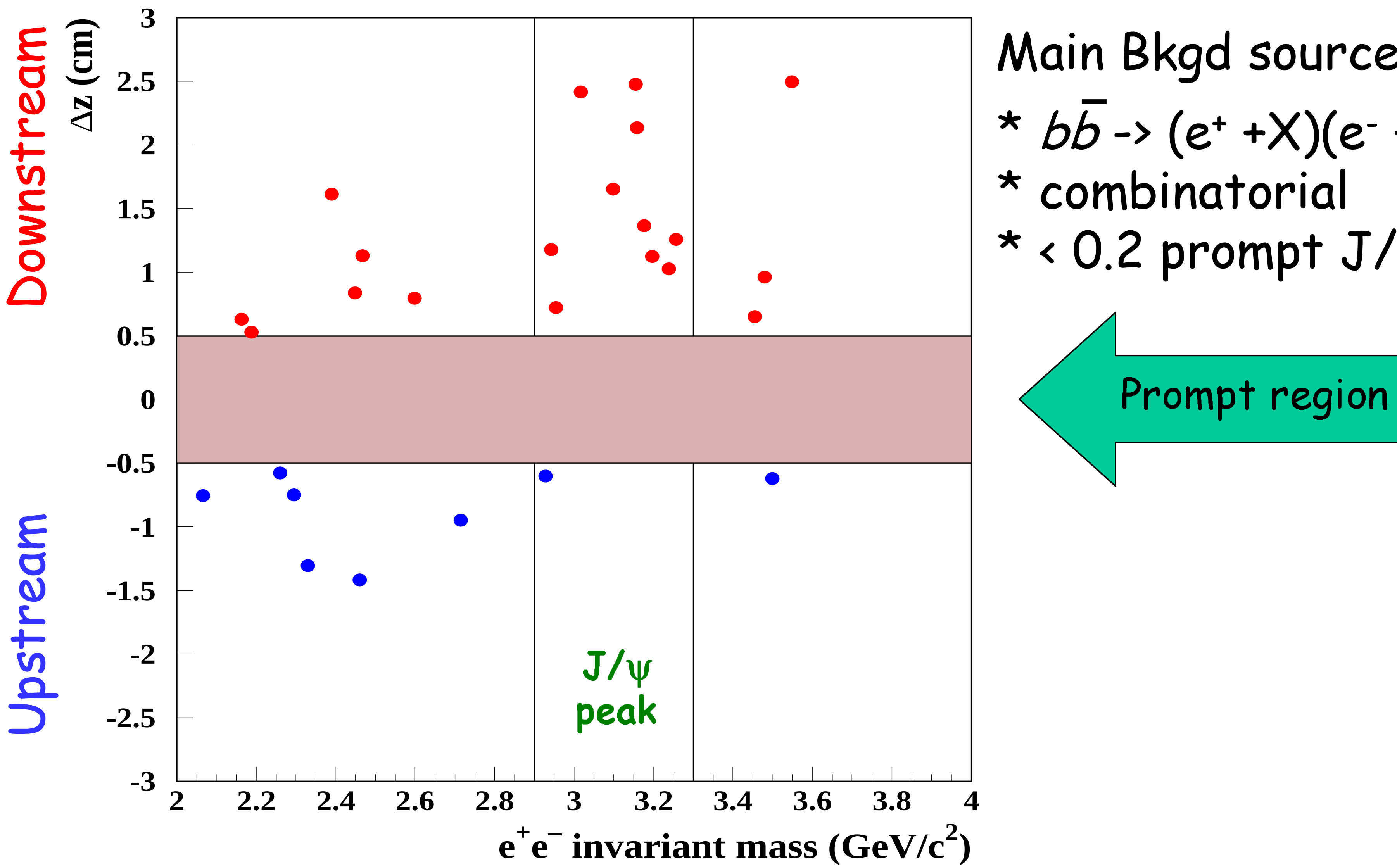
(600 μm) (8000 μm)







Detached b selection (e channel)



Main Bkgd sources:

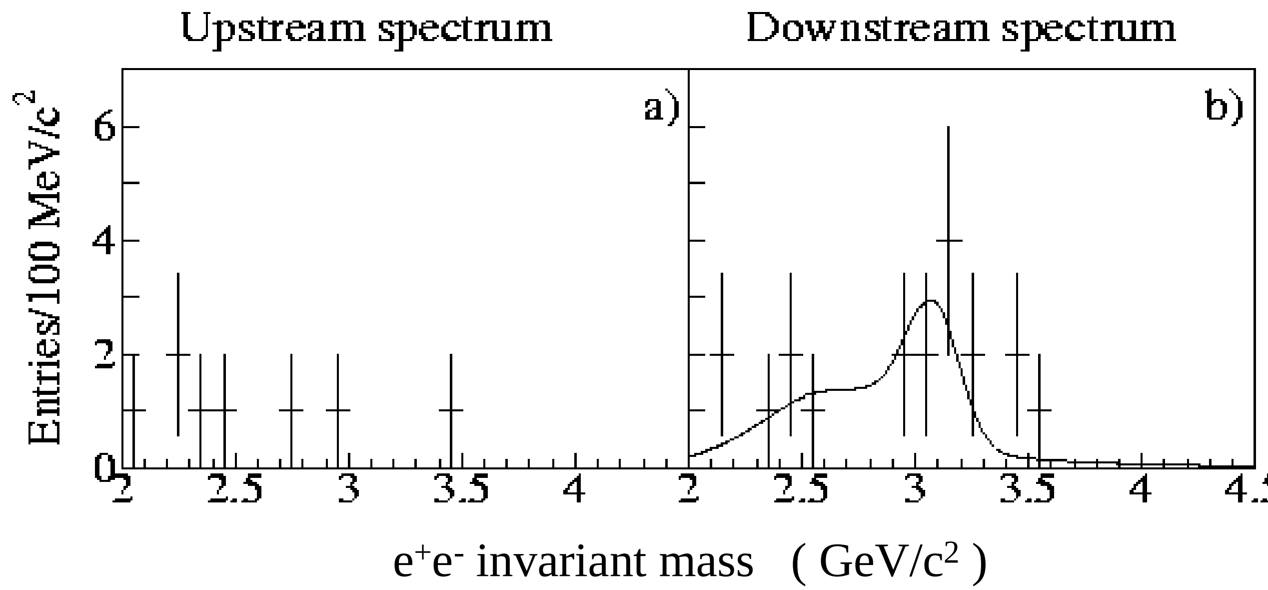
* $b\bar{b}$ -> (e^+ +X)(e^- +X
* combinatorial
* < 0.2 prompt J/ψ

Invariant Mass fit

Electron channel:

Unbinned Likelihood Fit:
- **Sig. shape from MC,**
- **BKG shape data/MC**

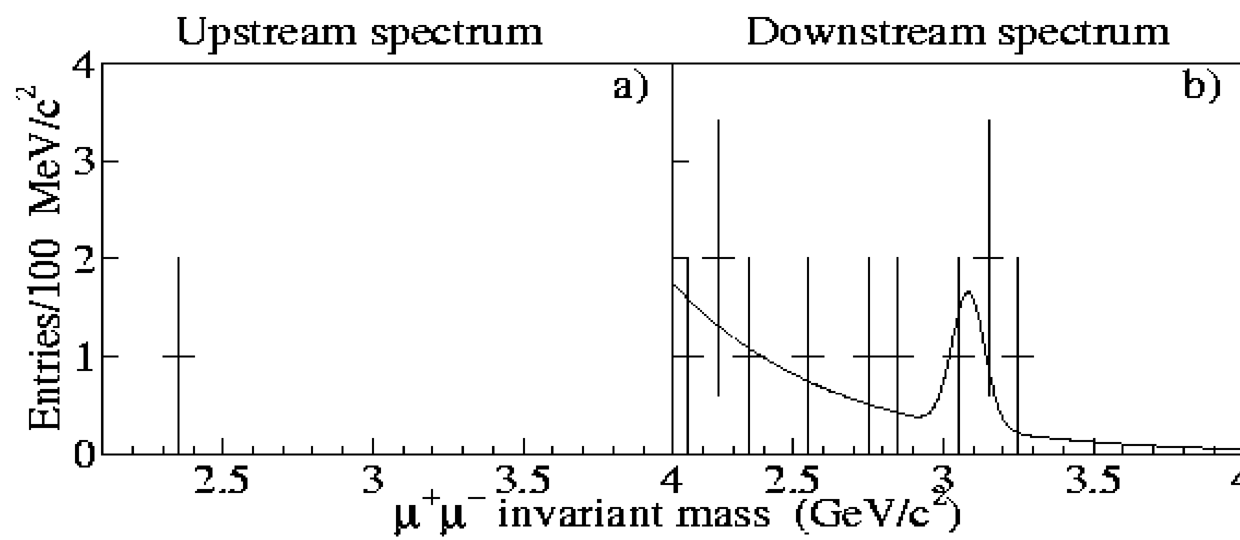
$$n_B = 8.6^{+3.9}_{-3.2}$$



Muon channel:

Unbinned Likelihood Fit:
- **Sig. shape from data,**
- **BKG shape from data**

$$n_B = 1.9^{+2.2}_{-1.5}$$



$\Delta\sigma(b\bar{b}) = 30^{+13}_{-11}$ (stat) **nb/nucl** *($-0.25 < x_F < 0.15$)*

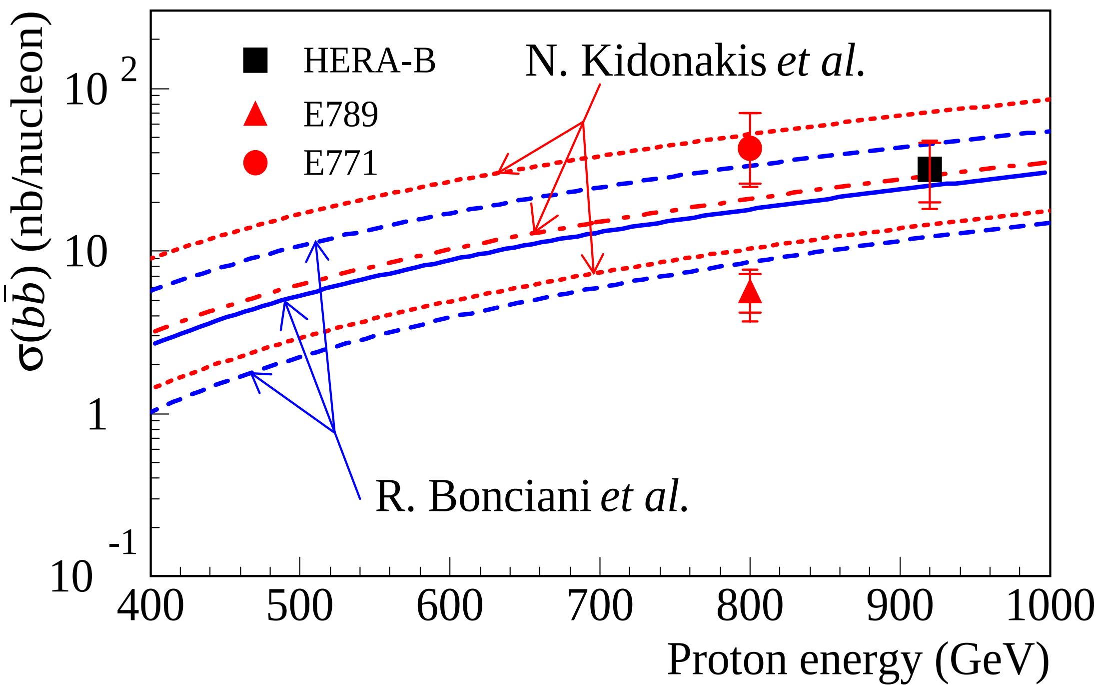
Systematic Uncertainties

External (internal) sources	Ch	Syst %
σ_r	eμ	11
BR(bb→J/ψX)	eμ	9
Trigger & detector sim. (ε_R)	eμ	5
b production/decay models MRST NNLL Parton Distr. F., Peterson Fragment., Pythia)	eμ	5
Prompt counting J/ψ (n_p)	e	5
Prompt J/ψ MC prod. Mod.	eμ	2.5
A-dependence in $\varepsilon_R \varepsilon^{\Delta z}{}_B$	eμ	1.7
Partial contribution	e-μ	17-16

Sources dominated by statistics	Ch	Syst %
$\mu^+\mu^-$ bkg fluctuations	μ	+10 -24
e^+e^- bkg shape	e	7
e^+e^- bkg fluctuations	e	11
Partial contribution	e-μ	$13\,^{+10}_{-24}$

Total systematic uncertainty	eμ	+20 % -23 %

Hera-B compared to other data/theory



Hera-B Y2K @ 920 GeV:

$\sigma_{TOT}(b\bar{b}) =$

$32 \,^{+14}_{-12}\,\text{(stat)}\,^{+6}_{-7}\,\text{(syst)}$ **nb/nucl**

(92% $b \rightarrow J/\psi$ in our x_F range)

The result shows good agreement with recent calculations beyond NLO

R. Bonciani *et al.* (2002),
NLO+NLL with latest MRST PDF
Nucl.Phys.B529 (1998)

N. Kidonakis *et al.* (2001),
NLO+NNLL
Phys.Rev D64 (2001) 114001-1

Conclusions

➔ $B \to J/\psi\ X \to l^+l^-X$ observed at Hera-B

➔ Result: $\sigma(b\bar{b}) = 32^{+14}_{-12}(stat)\,^{+6}_{-7}(sys)$ nb/nucleon

➔ Good compatibility with recent QCD calculations

➔ Outlook 2002/3: O(1000) higher statistics !

➔ Baseline Physics program
- $\sigma(b\bar{b})$: expected error 15% (systematic limited)
- Charmonium production ($J/\psi, \psi', \chi_c$), Atomic number dependence

Detector characteristics (I)

- ★ Large acceptance: 15-220 mrad in x (bending plane),
  15-160 mrad in y (vertical plane)
- ★ Target – up to 8 wires inserted into the halo of 920 GeV proton beam (C, Ti)
- ★ VDS – Vertex Detector System.
  Dilepton vertex resolutions: $\sigma_z \approx 600\ \mu m$, $\sigma_{x,y} \approx 70\ \mu m$
- ★ Dipole Magnet- field integral 2.13 Tm
- ★ OTR – Outer Tracker. Honeycomb drift cells; wire pitch 5/10 mm; spatial hit resolution ≈ 350 μm;
  Backward hemisfere in CM (negative x_F)
  World largerst honeycomb tracker: 1000 modules, 115000 channels
- ★ ITR – Inner Tracker: MicroStrip Gas Chambers, pitch 100 μm, resolution 100 μm;
  Forward hemisfere in CM (positive x_F)
  World largerst (gas) micro pattern tracker

Detector characteristics (II)

- ★ RICH – Ring Imaging Cherenkov Hodoscope
  C_4F_{10} radiator gas, 2 planes of PMT
  4σ separation: e/π $p \in [3.4, 15]$ GeV/c, π/K $p \in [12,54]$ GeV/c
- ★ ECAL – Electromagnetic CALorimeter – Sandwich sampling calorimeter ("Shashlik"); Pb and W as converter; 3 regions
- ★ MUON detector – 4 tracking stations; Gas pixel chambers, Proportional tube chambers, some with segmented cathodes
- ★ DAQ system – High bandwidth, high trigger and logging rates
- ★ TRIGGER.
  - Pretriggers on ECAL & MUON seeds
  - FLT hardware based on ITR/OTR
  - SLT software trigger; Tracking+Vertexing; linux farm with 240 nodes
- ★ Event reconstruction; on-line, linux farm with 200 nodes

The cross section normalization

[-0.25<x_F<0.15]

$$\Delta\sigma(b\bar{b}) = \sigma_r f \frac{n_B}{n_P} \frac{1}{\varepsilon_R \cdot \varepsilon_B^{\Delta z} \cdot Br(b\bar{b} \to J/\psi\ X)}$$

$$\varepsilon_R = \frac{\varepsilon_B}{\varepsilon_P}$$ Relative detection efficiencies

$\varepsilon_B^{\Delta z}$ Efficiency of detected vertex selection

n_B, n_P Number of observed $b \to J/\psi$ and prompt J/ψ

$$\sigma_r = \sigma(pN \to J/\psi\ X)\frac{A^{\alpha}}{A} = 314 \pm 7_{stat} \pm 31_{sys} \text{nb / nucleon}$$

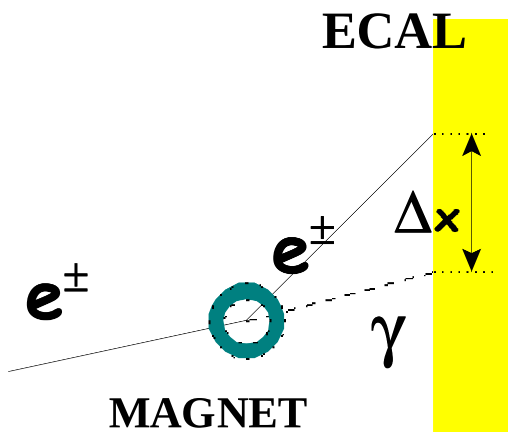
$f = 72\%$

E866 : 0.955 ± 0.005

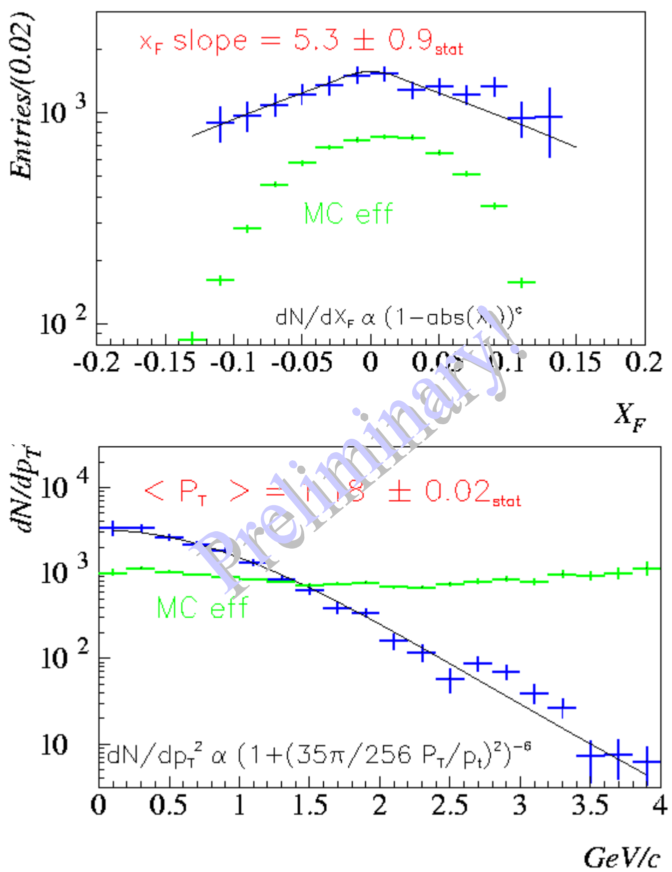
E789 + E771 : 356 ± 7 ± 25 nb/nucleon

Prompt J/ψ: Particle ID / Kinem.

Electron Channel: PID: E/P + bremsstrahlung



$\varepsilon_{BR}=0.34\pm0.02\pm0.02$



Muon Channel: PID: μ likelihoods from MUON and RICH detectors

Detached $b \rightarrow J/\psi$ cuts

Optimization procedure: $S_{MC} / \sqrt{BKG_{REAL}}$

Electron Channel Cuts: $\varepsilon_R \varepsilon_B^{\Delta z} = 0.44 \pm 0.02$

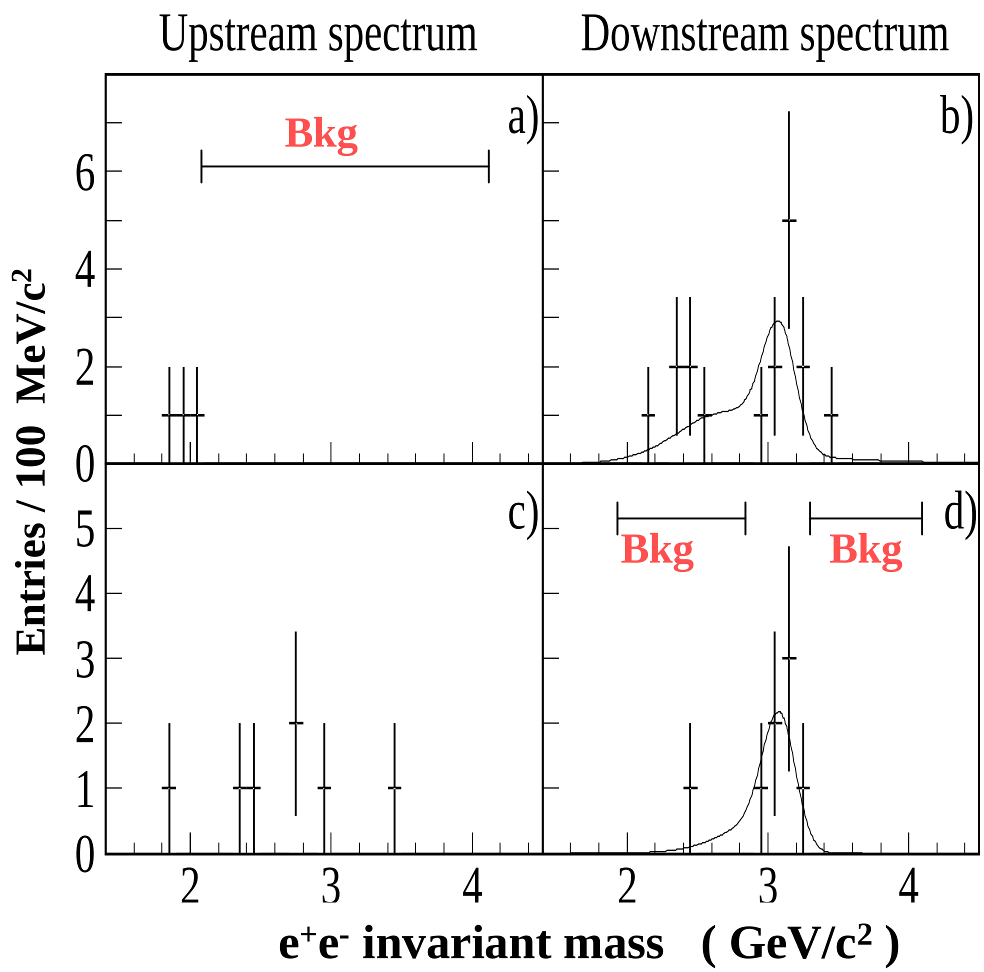
- Δz > 0.5 cm
- $e^{\pm}$ Imp. Param. wire I_w > 200 μm , or
- Min. dist. @ Z_W to any other track > 250 μm

Muon Channel Cuts: $\varepsilon_R \varepsilon_B^{\Delta z} = 0.41 \pm 0.01$

- Δz > 7.5 σ_z
- $\mu^{\pm}$ Imp. Param. to wire I_w >45μm
- $\mu^{\pm}$ " " to primary vtx I_p> 160μm

Systematic checks (e-channel

Different bkg optimization:

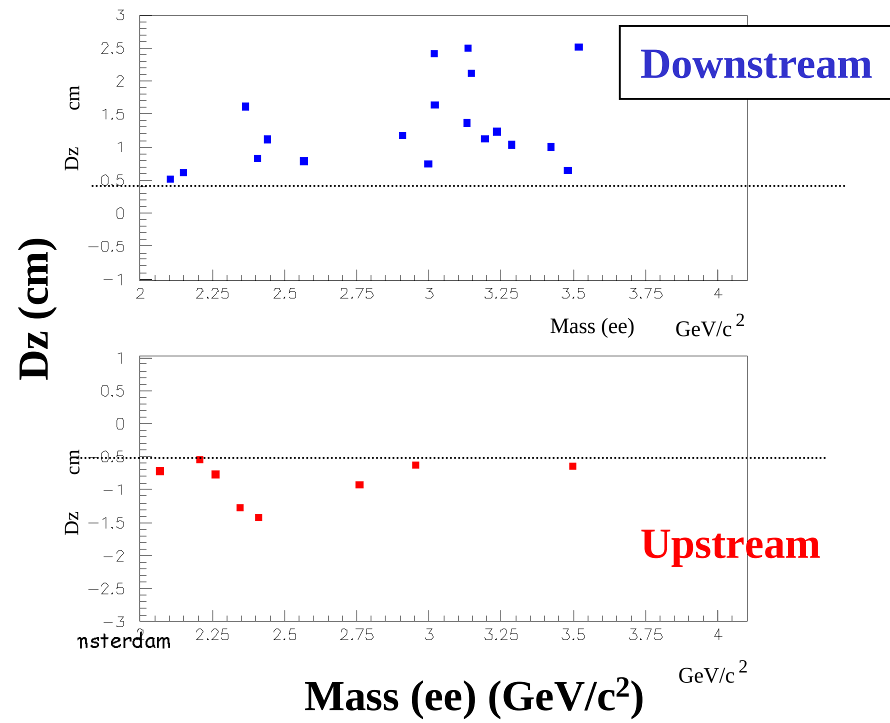


DECAY LENGTH LIKELIHOOD FIT:

$\lambda_{MC} = 0.81 \pm 0.03$ cm

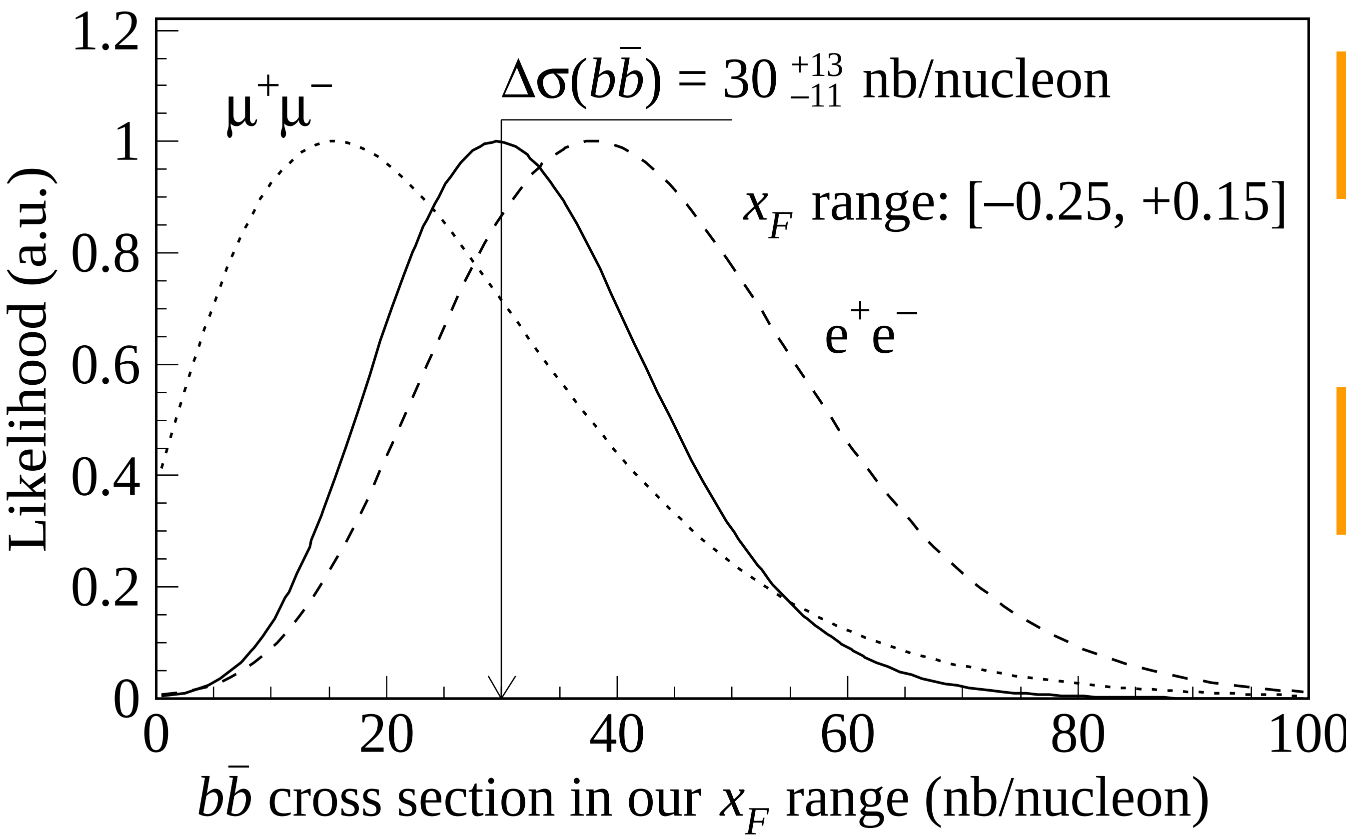
$\lambda_{RD} = 1.00 \pm 0.30$ cm

$\lambda_{BKG} = 0.36 \pm 0.13$ cm



$\sigma(b\bar{b})$ Determination

Simultaneous fit to e^+e^- & $\mu^+\mu^-$ (in Hera-B acceptance):



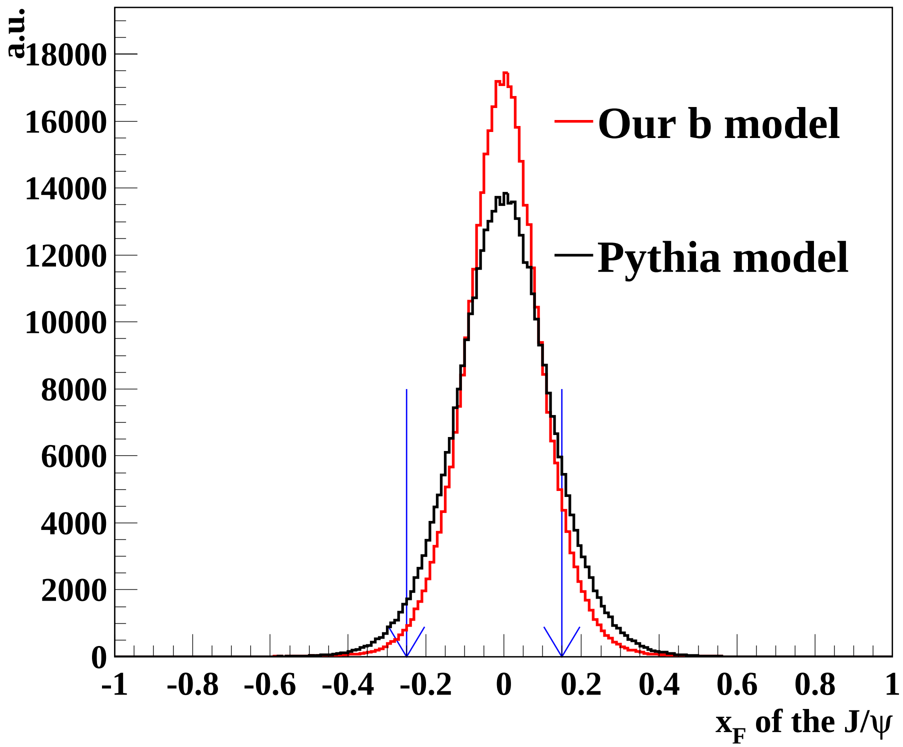
e-channel ⇒ $\Delta\sigma(b\bar{b}) = 38\ ^{+18}_{-15}$ nb/N

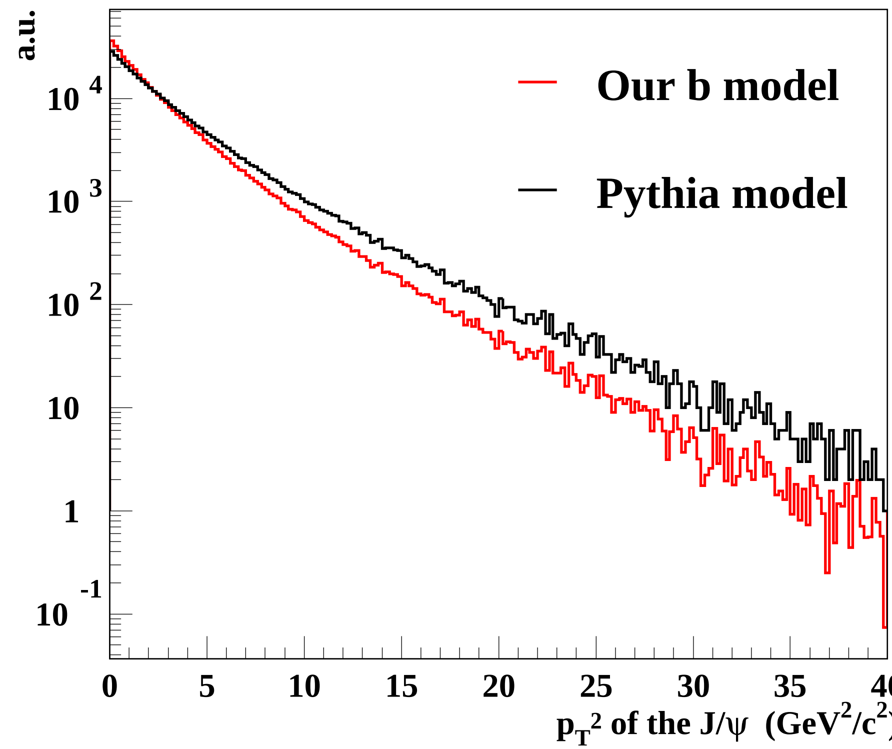
μ-channel ⇒ $\Delta\sigma(b\bar{b}) = 16\ ^{+18}_{-12}$ nb/N

Extrapolation to the full x_F range:

$\sigma_{TOT}(b\bar{b})$: $32\ ^{+14}_{-12}$ (stat) $^{+6}_{-7}$ (syst) **nb/nucleon**

J/ψ from *b* decays kinematics





92% of J/ψ are produced in our x_F range

b production model

For the x_F and p_T distributions of J/ψ from b decays,
we need a model of the b quark production and hadronization

Our b production & decay model:

- Based on HQ cross section calculation at NLO+NLL by
  M. Mangano, P. Nason and G. Ridolfi, Nucl. Phys. B373 (92) 295

  $\mathbf{m}_b = \mathbf{4.75\ GeV/c^2}$ $\mu = \sqrt{\mathbf{m}_b^2 + \mathbf{p}_T^2}$
- Latest MRST parton distribution functions (NNLL) for nucleons
- Intrinsic k_T of interacting partons is gaussian-distributed
  with $\langle k_T^2 \rangle = 0.5\ GeV^2$
- b quarks fragmentation given by a Peterson function (ε = 0.006)
- The b-hadron decays to J/ψ is controlled by Pythia

92% of J/ψ from b decays are produced in our x_F range

b production model systematics

Default model: MRST PDF, Peterson FF ε=0.006

$m_b = 4.75\ \mathrm{GeV}/c^2 \qquad \mu_0 = \sqrt{m_b^2 + p_T^2} \qquad \langle k_T^2 \rangle = 0.5\ \mathrm{GeV}/c^2$

Studied variations:	Sys cont. to $\sigma(bb)$
• Changing PDFs from MRST to CTEQ	→ ±1.5%
• b quark mass from 4.5 to 5.0 GeV/c^2	→ ±1%
• QCD renormalization scale μ from 0.5 μ_o to 2 μ_o	→ ±2%
• Fragmentation functions	→ ±3%
– Peterson form with ε from 0.002 to 0.008	
– Kartvelishvili form with α_β from 12.4 to 15.0	
• $\langle k_T^2 \rangle$ from 0.125 to 2.0 GeV^2	→ ±1%
• Fraction of b-baryons produced in the b-hadronization process from 0 to 12%	→ ±2%

Total: ±5%

Essential Bibliography

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