INCLUSIVE b PRODUCTION IN pN INTERACTION AT 920 GeV WITH HERA-B

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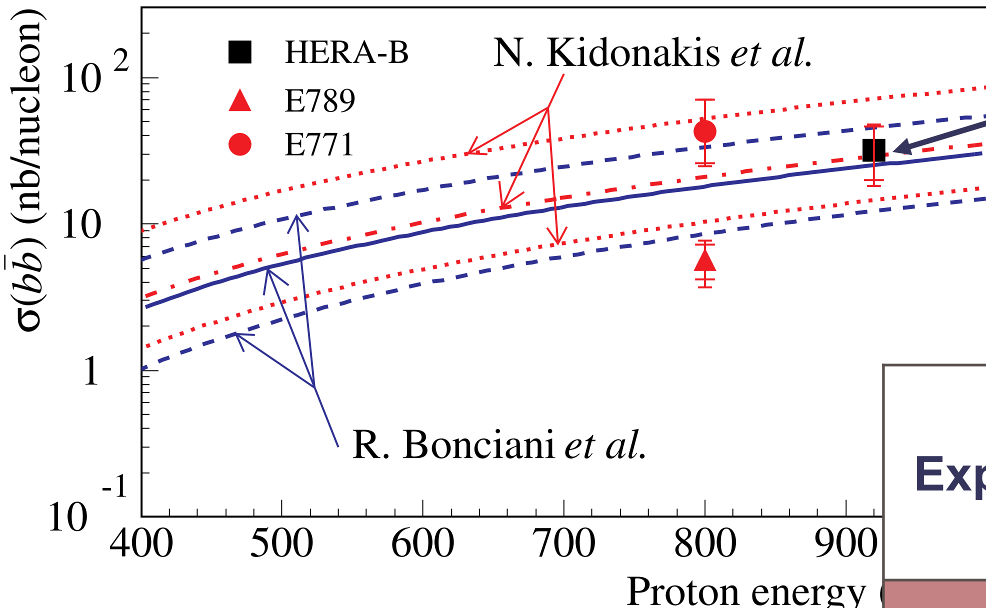
OUTLOOK

- Physics motivations of the measurement
- Detector performances
- Principle of the measurement
- $b\bar{b}$ cross section in the muon channel
- $b\bar{b}$ cross section in the electron channel
- Combined measurement
- b-lifetime determination
- Discussion of the results
  - Comparison with previous measurements
  - Comparison with theoretical predictions
- Conclusions

PHYSICS MOTIVATIONS

- b-production at fixed-target close to kinematic threshold ($\perp$ high p_T regime)
  - **Experiments: low statistics, large systematic uncertainties**

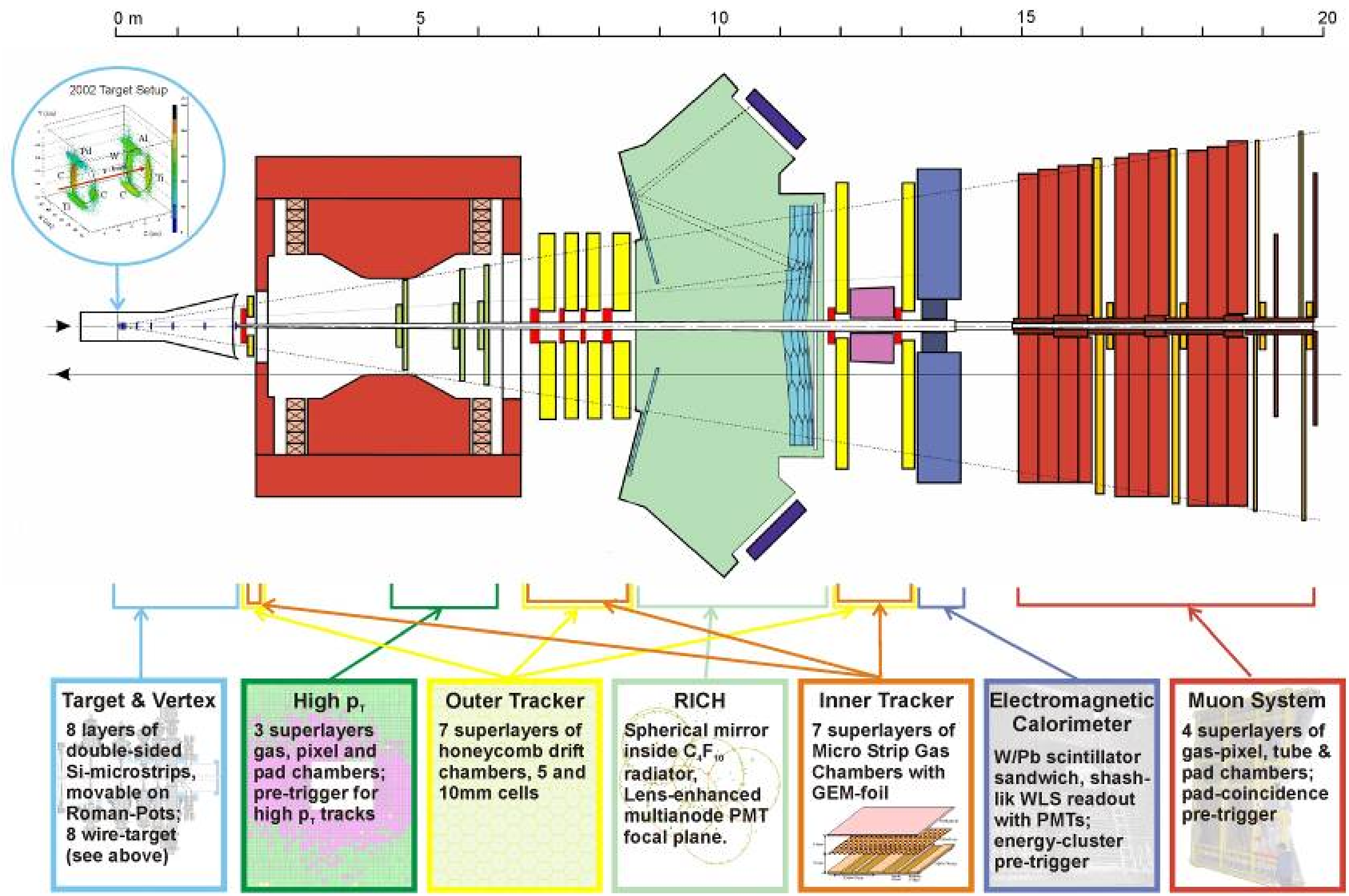


Y2000 measurement

Exp.	Target/ p-Beam (GeV/c)	$\sigma(bb)$ nb/nucleon	Channel
E789	**Au/800**	**$5.7 \pm 1.5 \pm 1.3$**	**$b \rightarrow J/\psi(\mu^{\pm})X$**
E771	**Si/800**	**$43^{+27}_{-17} \pm 7$**	**μ-semilept. bb decay**
HERA-B	**C-Ti/ 920**	**32^{+14+6}_{-12-7}**	**$b \rightarrow J/\psi(\mu^{\pm}/e^{\pm})X$**

  - **Theory: large uncertainties (soft gluon resummation, b quark mass)**
  - **Precise measurements can allow tests of QCD models**

THE HERA-B DETECTOR

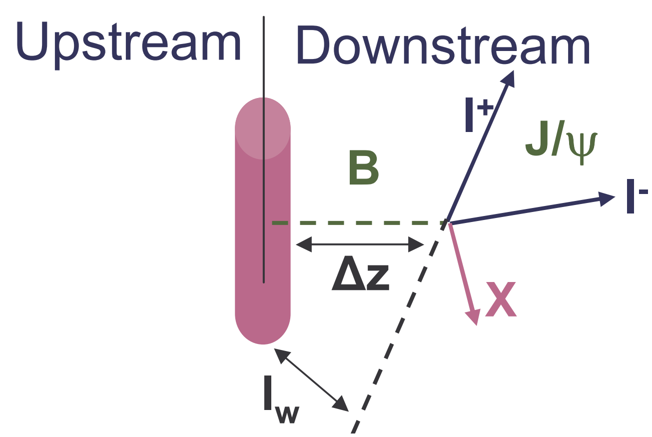


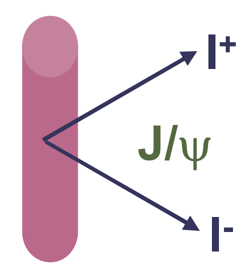
THE HERA-B DETECTOR

- Fixed target detector at e-p ring HERA, Desy
- High rate forward spectrometer (< 40MHz)
- Wire targets (different materials: C,W,Ti) in proton halo
- Proton beam at 920 GeV/c ($\sqrt{s}$ = 41.6 GeV)
- Multiple trigger level (Hardware + Software) for lepton pairs
- High resolution vertexing
- Very good particle ID for (e, μ, π, K, p)
- On-line event reconstruction

PRINCIPLE OF THE MEASUREMENT (I)

- Observe the $b \rightarrow J/\Psi(\mu^+\mu^-/e^+e^-)+X$ decay channel in X_F, P_T acceptance ($-0.35<X_F<0.15$, $P_T<5$ GeV/c)
  - Clear J/Ψ signal observable
  - Electron and muon J/Ψ decay available
    - Internal cross check (2 independent measurements)
    - Control of systematics uncertainties
  - Long mean path for b-hadrons @ HERA-B (≈ 8000 μm)
    - Detached analysis possible if prompt J/psi rejection is high





PRINCIPLE OF THE MEASUREMENT (II)

- Measurement relative to prompt J/Ψ x-section
  - Minimize systematics uncertainties
  - Independent of Lumi determination
  - Mostly independent of production model and J/Ψ cross section

Atomic number x-section dependence

Δ=in detector acceptance

ε_R= relative efficiency ≈1

$$R_{\Delta\sigma} = \frac{\Delta\sigma(b\bar{b})}{\Delta\sigma(J/\psi)} = \frac{n(b\bar{b})}{Br(b\bar{b} \to J/\psi X) \cdot \sum_i n_P^i \cdot \varepsilon_{R,i} \cdot \varepsilon^{\Delta z}_{b\bar{b},i} \cdot A_i^{1-\alpha}}$$

Sum over target materials
C,W,Ti

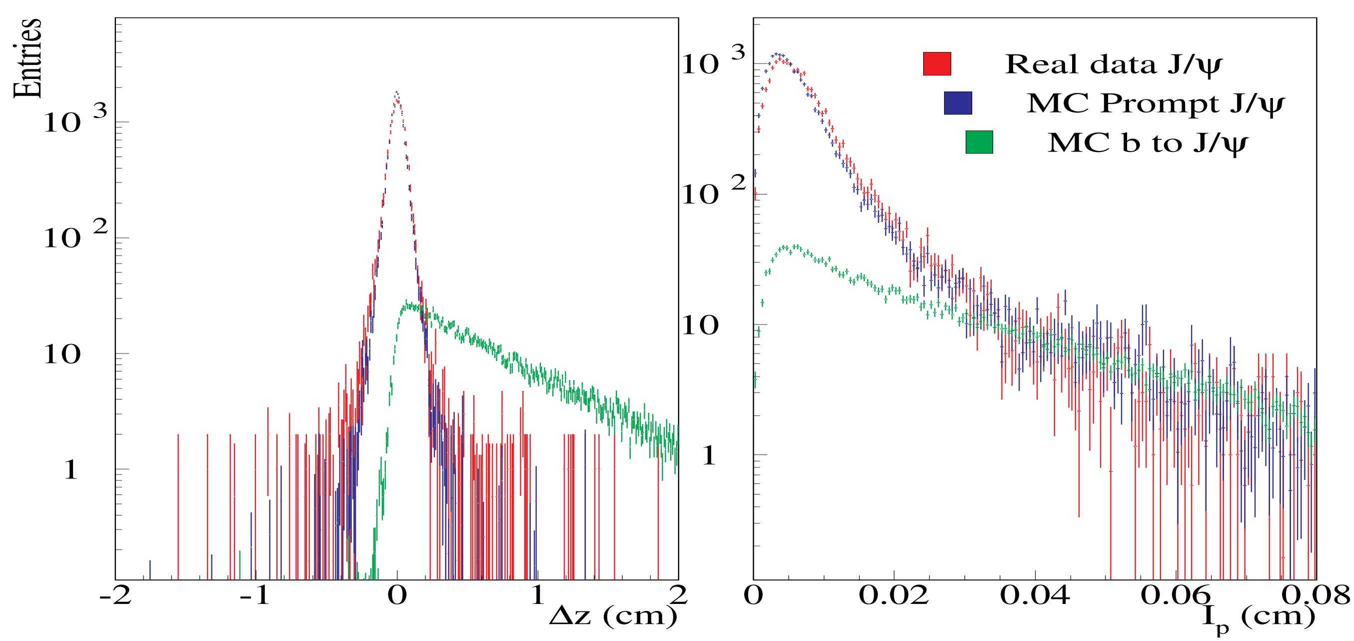
B selection efficiency from MC

DETECTOR PERFORMACES (I)

- Highly selective dilepton trigger:
  - pretriggers
    - high E_T ECAL clusters, MUON hit coincidences
  - FLT: hardware trigger
    - track finding behind magnet (Kalman filter)
  - SLT: software trigger
    - track finding behind magnet and in VDS
    - vertex reconstruction
  - online event reconstruction
- 165 M dilepton trigger events
  - ≈ 300.000 J/Ψ (>1000 per hour)
  - ≈ 20.000 χ_c

DETECTOR PERFORMACES (II)

- Di-lepton vertex resolution crucial for detached analysis
  - $\sigma_{\Delta z} \approx 450\ \mu m$ << b-mean path ($\approx 8000\ \mu m$)
  - Impact parameter provide further prompt J/Ψ rejection
  - Good MC description of real situation

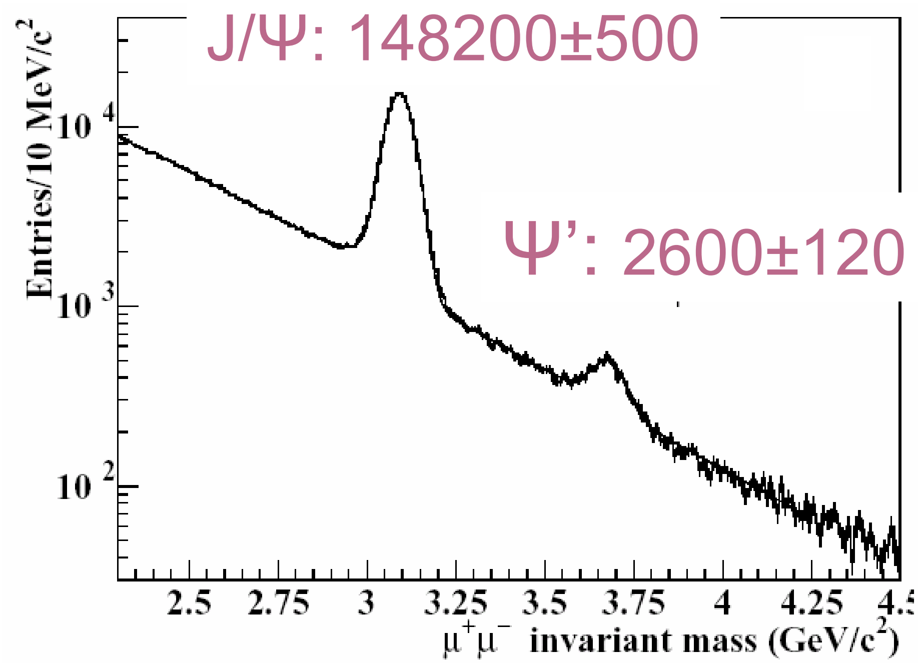


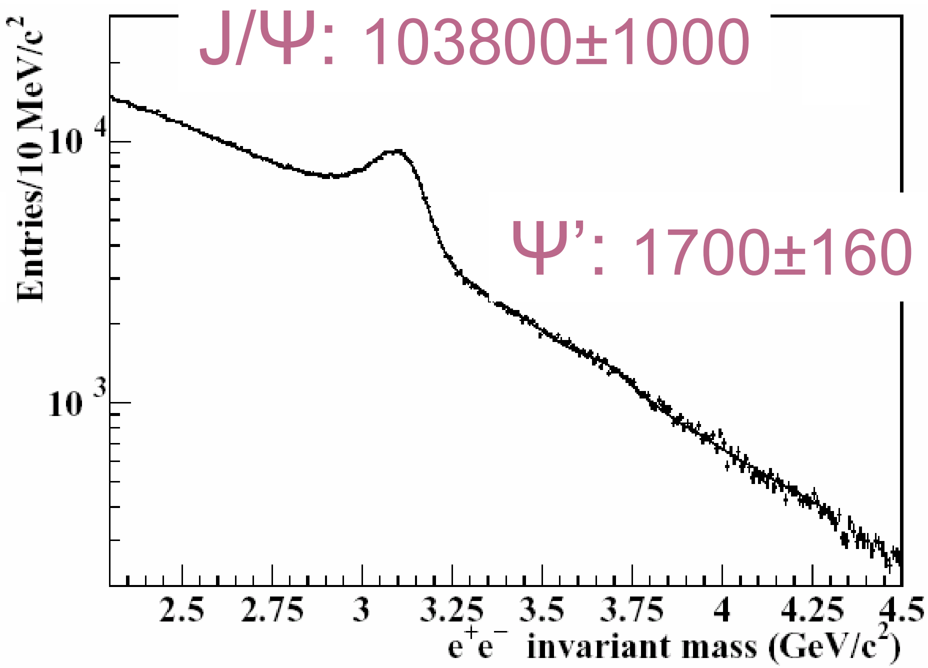
DATA SAMPLE

- Di-lepton trigger data
- 3 target wires used of different materials
  - Carbon (A=12, ≈ 64% of total statistics)
  - Tungsten (A=184, ≈ 27%)
  - Titanium (A=48, ≈ 9%)
- 9 different wire configurations used (single and double wire). MC simulation for all configurations
- Preselection of runs with stable conditions and smooth detector/beam operations

PROMPT J/Ψ SELECTION

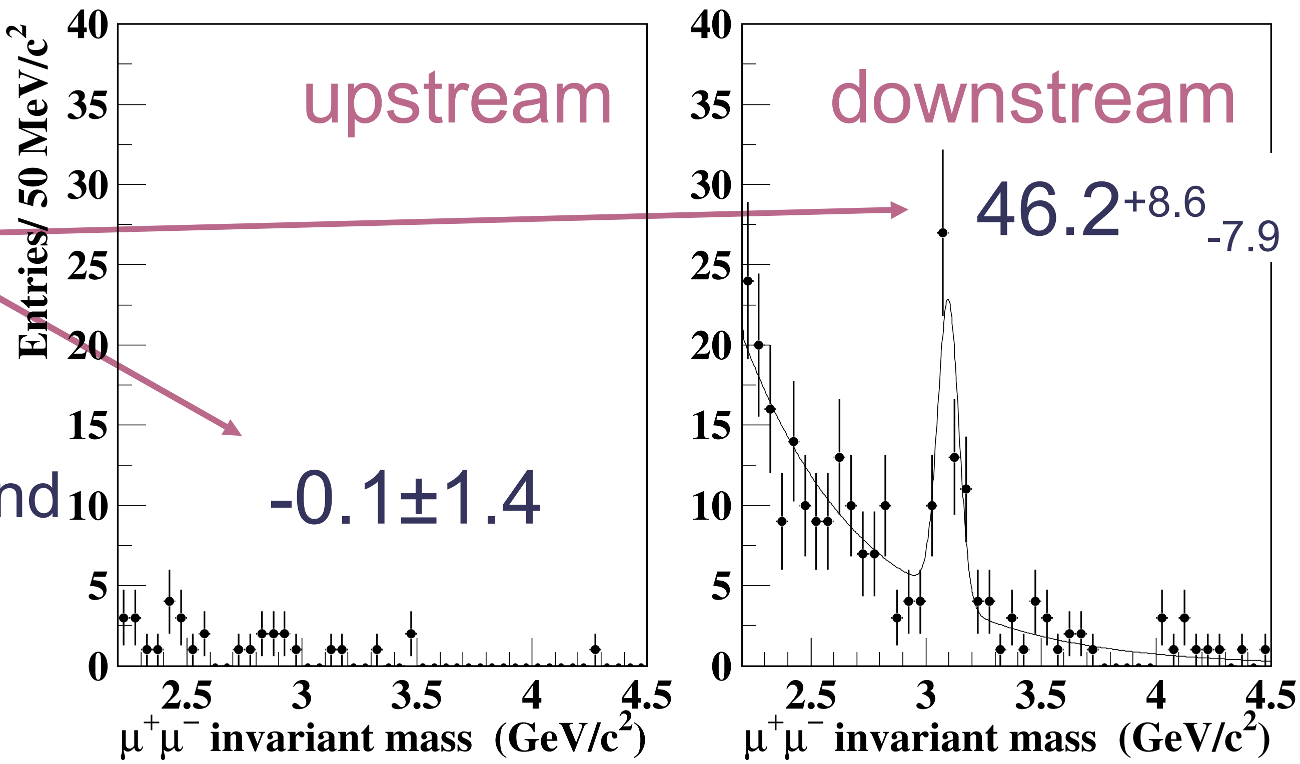
- Efficient lepton track and vertex reconstruction
  - Pχ2 > 1%
- Effective PID (μ-Likelihood; E/P)





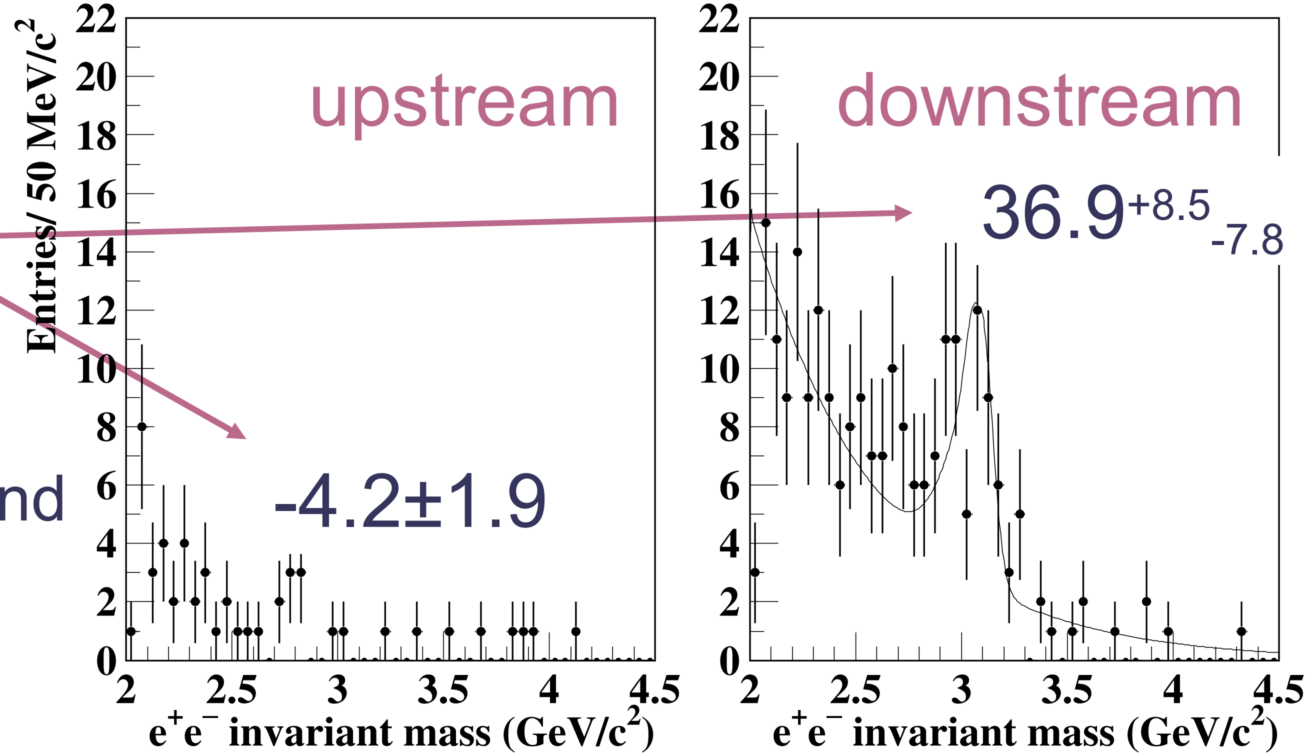
MUON CHANNEL: DETACHED J/Ψ

- Detachment cuts on significance of:
  - $\Delta z > 9\,\sigma$
  - $I_w^{\mu} > 2.6\,\sigma$
  - $I_w^{J/\Psi} < 9\,\sigma$
- Unbinned likelihood fit
- bck dominated by 2-semil. b and combinatorial
- No prompt J/Ψ bck survive



ELECTRON CHANNEL: DETACHED J/Ψ

- Detachment cuts on significance of:
  - $\Delta z > 10\ \sigma$
  - $I_w^{\mu} > 3.0\ \sigma$
  - $I_w^{J/\Psi} < 12\ \sigma$
- Unbinned likelihood fit
- bck dominated by 2-semil. b and combinatorial
- No prompt J/Ψ bck survive



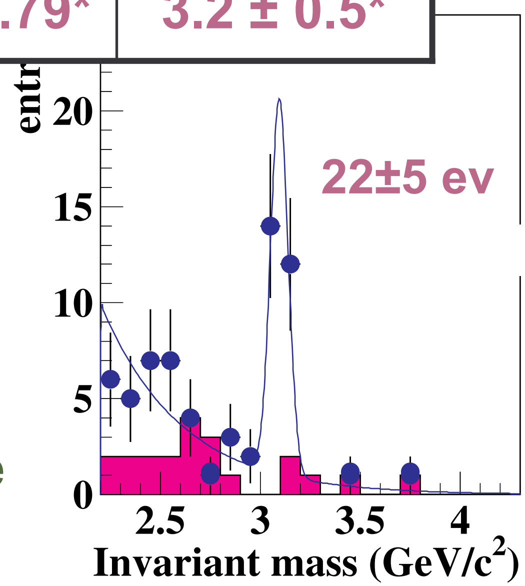
SEPARATE AND COMBINED ANALYSIS

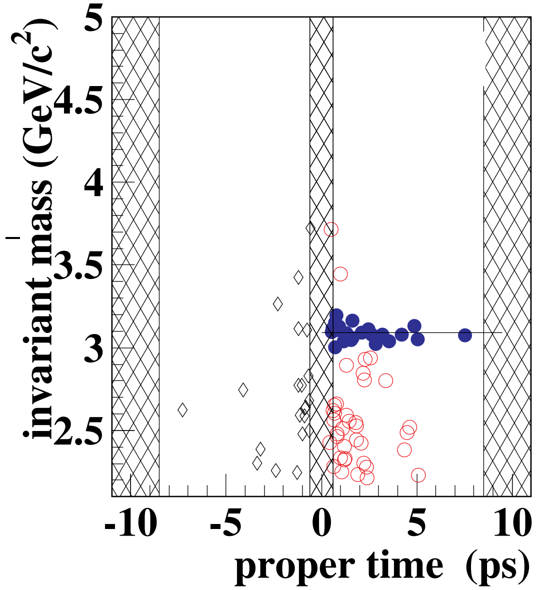
- e and μ channels independent
  - Results compatible within errors
  - Combined analysis: reduce errors & control systematics

	$\mu^+\mu^-$	e^+e^-	$\mu^+\mu^-$& e^+e^-
$R_{\Delta\sigma}$ ($\times10^{-2}$)	3.01±0.57*	3.60±0.79*	3.2 ± 0.5*

* Statistical errors only

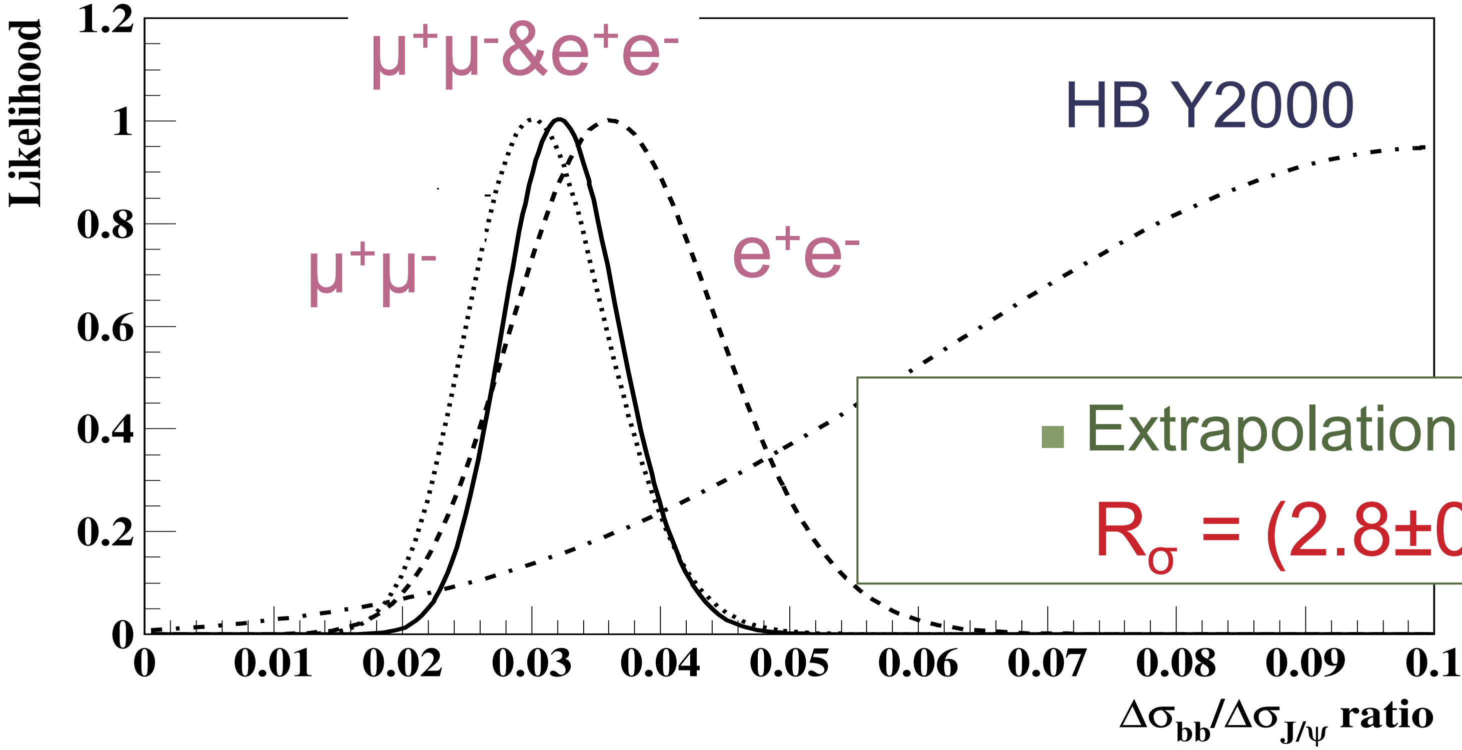
- Search for $J/\Psi+h^\pm$
  - Relax detachment cuts
  - Search for additional tracks
  - partially independent sample
  - higher purity but lower stat.
  - $R_{\Delta\sigma} = (4.3\pm1.0)\times10^{-2}$ compatible with main result





FINAL RESULT

- Total systematic uncertainty 14%
- Present result 1.6σ below Y2000 Hera-b value
- Including former result $R_{\Delta\sigma} = (3.3 \pm 0.5 \pm 0.4) \times 10^{-2}$



- Extrapolation to full xf:

$R_{\sigma} = (2.8 \pm 0.4 \pm 0.3) \times 10^{-2}$

SYSTEMATIC ERROR EVALUATION

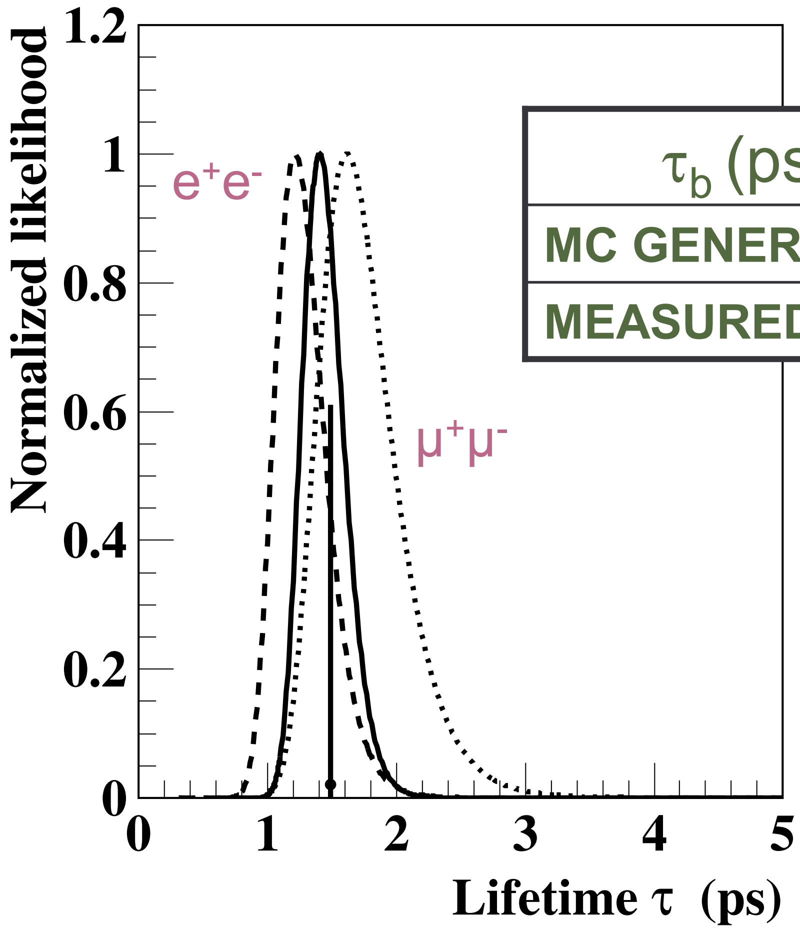
- Systematic uncertainties both internal and external to the analysis

Source	$\mu^+\mu^-$	e^+e^-
Br($bb \rightarrow J/\Psi+X$)	8.6%	
ε_R	5%	
B prod. & decay model	3.1%	
J/Ψ prod. & decay model	1.5%	
Analysis cut & procedure	<5%	
Background shape	<1%	7%
TOTAL (on average meas.)	14%	

- Statistical fluctuations (15%) dominated by detached J/ψ counting

LIFETIME DETERMINATION

- Clear test of candidates b-nature
- Unbinned likelihood fit including efficiency dependence



τ_b (ps)	$\mu^+\mu^-$	e^+e^-	COMBINED
MC GENERATED		1.56±0.01	
MEASURED	1.61±0.27	1.21±0.18	1.41±0.16

- Upstream and off-mass events lifetime incompatible with τ_b
- Standard χ^2 fit provides:

τ_b=1.39± 0.19 ps

PROMPT J/Ψ CROSS SECTION

- Reference J/Ψ cross section @ √s = 41.6 GeV needed to obtain absolute b-cross section

$$\boxed{R_\sigma = \frac{\sigma(b\bar{b})}{\sigma(J/\psi)} = (2.8 \pm 0.4 \pm 0.3) \times 10^{-2}}$$

- Experimental results exist from √s ~6 to ~200 GeV
- Inconsistencies among various measurements
- Work ongoing to fit existing results with COModel based parametrisation
- σ(J/Ψ) parameter is external to the present analysis

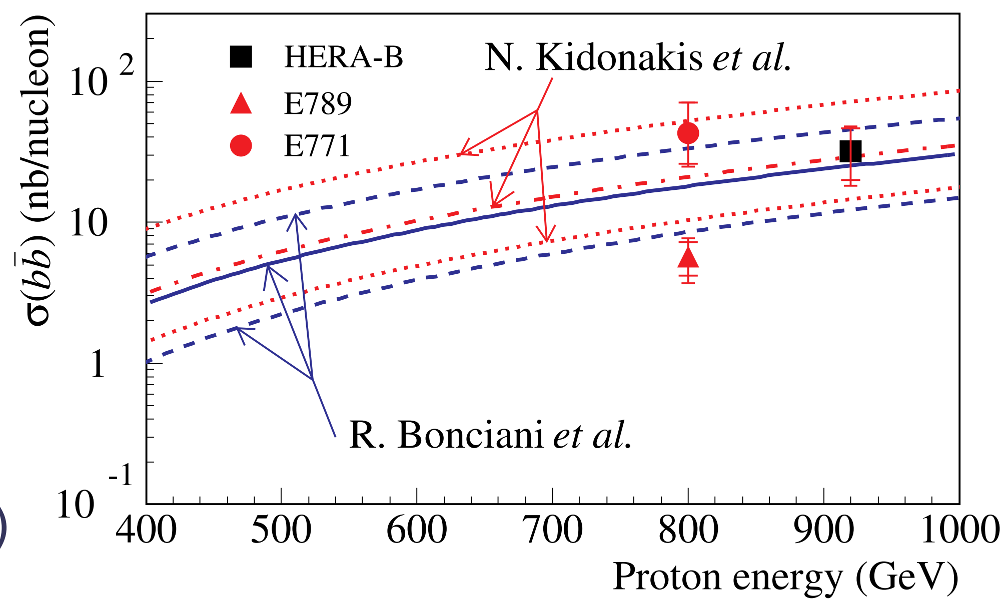
DISCUSSION OF RESULTS (I)

- Measurement of $R_{\Delta\sigma}$ and R_σ are self-contained and weekly dependent on external parameters/models

BUT

- straightforward comparison with QCD calculation difficult
  - Theoretical calculations concern $\sigma(b\bar{b})$
- $\sigma(b\bar{b})$ result and comparison with predictions available soon

(depend on $\sigma(J/\Psi)$ determination)



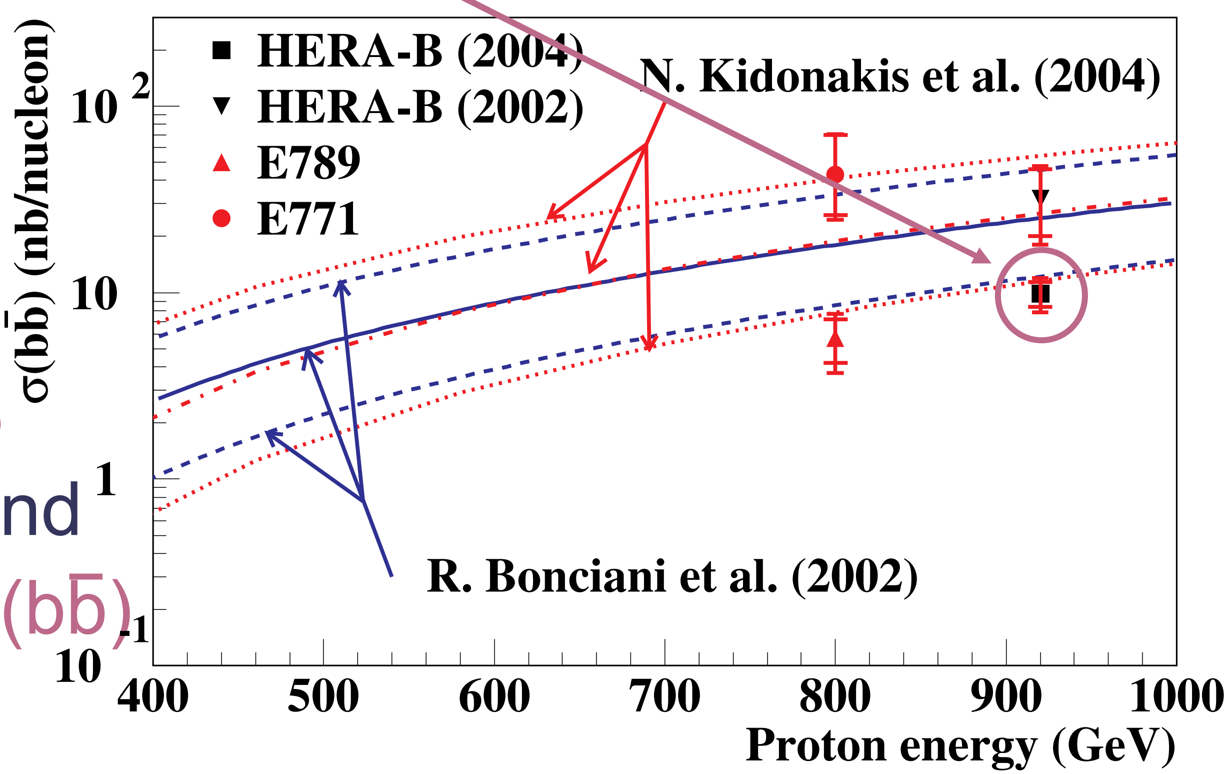
DISCUSSION OF RESULTS (II)

- Using $\sigma(J/\Psi)=(352 \pm 2 \pm 26)$ nb/n from E789/E771 we obtain

$$\boxed{\sigma(b\bar{b}) = (9.9\pm1.5\pm1.4)\ \text{nb/n}}$$

BUT

- Ongoing study suggests ~40% higher $\sigma(J/\Psi)$ and consequently $\sigma(b\bar{b})$



CONCLUSIONS

- Search for $b \rightarrow J/\Psi(\mu^+\mu^-/e^+e^-) + X$ to measure $R_{\Delta\sigma}$
  - Measurement mostly independent of theoretical models
- $46.2^{+8.6}_{-7.9}$ and $36.9^{+8.5}_{-7.8}$ candidates in $\mu^+\mu^-$ and e^+e^-
  - Highest statistics measurement existing at fixed target
- $R_{\Delta\sigma} = (3.2 \pm 0.5 \pm 0.4) \times 10^{-2}$ is measured.
  - Combining with Y2000 Herab result $R_{\Delta\sigma} = (3.3 \pm 0.5 \pm 0.4) \times 10^{-2}$
  - Extrapolation to full x_F provides $R_\sigma = (2.8 \pm 0.4 \pm 0.3) \times 10^{-2}$
- Lifetime measurement gives $\tau_b = 1.41 \pm 0.16$ ps
  - In agreement with expectations
- Ongoing fit of existing experimental results on $\sigma(J/\Psi)$ with COM parametrisation to provide absolute bb cross section value.

BACK-UP SLIDES

MUON AND ELECTRON CHANNEL: RELATIVE X-SECTION RESULTS

Channel	$\mu\mu$			ee		
Target	C	Ti	W	C	Ti	W
Atomic weight	12	47.87	183.84	12	47.87	183.84
n_p	91850±300	8080±100	45380±200	67100±700	4800±200	32400±600
n_{bb}	27.8±6.3	3.0±2.1	15.5±4.5	$17.8^{+5.8}_{-5.2}$	0.9±1.0	$18.4^{+6.2}_{-5.5}$
$\langle\varepsilon_R\varepsilon_{\Delta z}\rangle$	0.390(4)	0.389(11)	0.396(5)	0.359(7)	0.416(21)	0.394(13)
α	0.96			0.96		
$Br(bb \rightarrow J/\Psi X)$	2.32±0.20					
$R_{\Delta\sigma}^{A}(\times 10^{-2})$	3.32±0.78	4.2±2.9	3.8±1.2	3.3±1.0	1.9±2.3	6.4±2.1
$R_{\Delta\sigma}(\times 10^{-2})$	3.01±0.57			3.60±0.79		

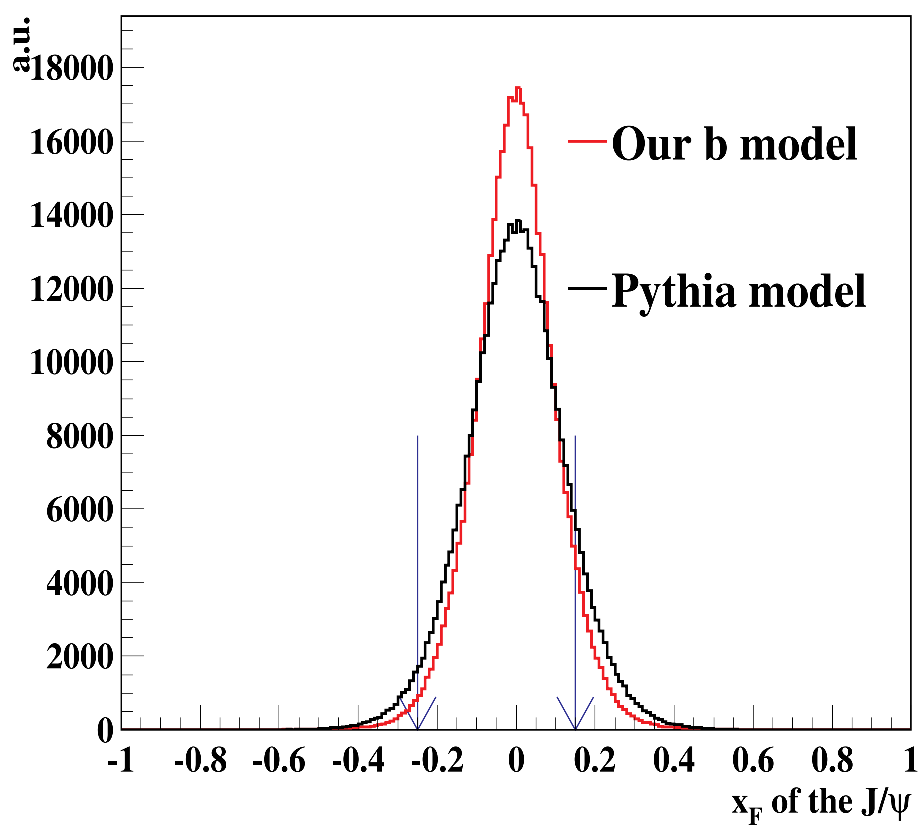
b-PRODUCTION MODEL: SYSTEMATICS

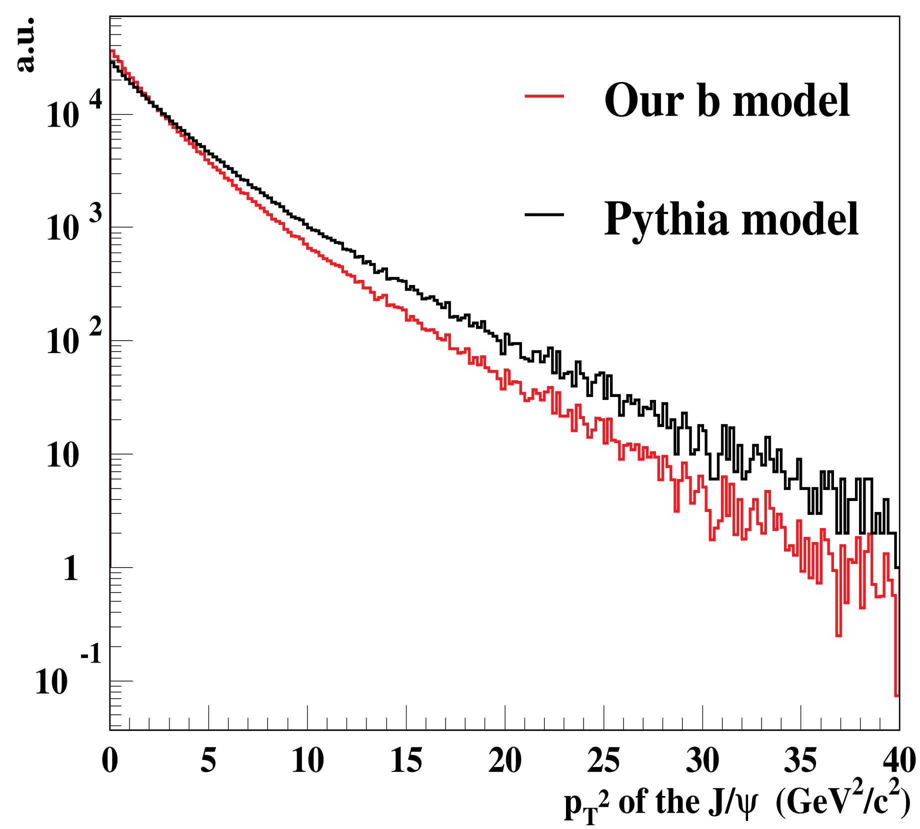
Default model: MRST PDF, Peterson FF e=0.006

$m_b = 4.75\ GeV/c^2 \qquad \mu_0 = \sqrt{m_b^2 + p_T^2} \qquad < k_T^2 >= 0.5\ GeV/c^2$

VARIATIONS on USED MODEL	SYST.CONTRIB
Changing PDFs from MRST to CTEQ	±1.5%
b quark mass $\in$ [4.5 - 5.0] GeV/c^2	±1.0%
QCD renormalization scale m $\in$ [0.5 – 2.0] m_o	±2.0%
FF: Peterson with *e* $\in$ [0.002 - 0.008] & Kartvelishvili with $a_b \in$ [12.4 - 15.0]	±3.0%
$<k_T^2>$ $\in$ [0.125 - 2.0] GeV^2	±1.0%
Fraction of *b*-baryons in hadronization process $\in$ [0 to 12] %	±2.0%
TOTAL	±5.0%

J/ψ FROM *b*-DECAYS: KINEMATICS





91% of J/ψ are produced in our x_F range

DETECTOR CHARACTERISTICS (I)

- Large acceptance
  - [15-220] mrad in x (bending plane)
  - [15-160] mrad in y (vertical plane)
- TARGET
  - up to 8 wires into the halo of 920 GeV proton beaM (C, Ti, W)
- VDS (Silicon Vertex Detector System)
  - Dilepton vertex resolutions: $s_z \approx 600$ mm, $s_{x,y} \approx 70$ mm
- Dipole Magnet
  - field integral 2.13 Tm
- OTR (Outer Tracker)
  - Honeycomb drift cells; wire pitch 5/10 mm; spatial hit resolution $\approx$ 350 mm;
  - World largerst honeycomb tracker: 1000 modules, 115000 channels
  - Large negative x_F coverage (x_F >-0.35)

DETECTOR CHARACTERISTICS (II)

- ITR (Inner Tracker)
  - MicroStrip Gas Chambers, pitch 100 mm, resolution 100 mm;
  - World largerst (gas) micro pattern tracker
  - Forward hemisfere in CM (positive x_F)
- RICH (Ring Imaging Cherenkov Hodoscope)
  - C_4F_{10} radiator gas, 2 planes of PMT
  - 4σ separation: e/p ([3.4-15] GeV/c), p/K ([12-54] GeV/c)
- ECAL (Electromagnetic CALorimeter)
  - Shashlik sampling calorimeter; 3 sections (W, Pb as converter)
  - Spatial resolution (1.25→2.17) cm stch. term $\oplus$(0.02→0.28) cm
  - Energetic resolution (10.8→20.5)% stch. term $\oplus$(1.2→1.4)%

DETECTOR CHARACTERISTICS (III)

- MUON Detector
  - 4 tracking stations
  - Gas pixel chambers + Proportional tube chambers
- DAQ System
  - High bandwidth, high trigger and logging rates
- TRIGGER System
  - Pretriggers on ECAL & MUON seeds
  - FLT hardware based on ITR/OTRSLT software trigger; Tracking+Vertexing;
  - linux farm with 240 nodes
- Event Reconstruction
  - on-line, linux farm with 200 nodes

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PRINCIPLE OF THE MEASUREMENT (II)

- Measurement relative to prompt J/Ψ x-section
  - Minimize systematics uncertainties
  - Measurement independent of Lumi determination

- pN → bb + X → J/ψ + XY → m^+m^-/e^+e^- + XY

ε_R= relative efficiency ≈1

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

B selection efficiency from MC