6th International Conference on Hyperons, Charm & Beauty Hadrons
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Open and Hidden Charm Production in 920 GeV Proton-Nucleus Collisions

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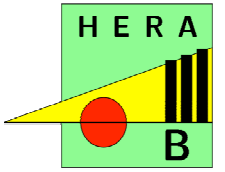
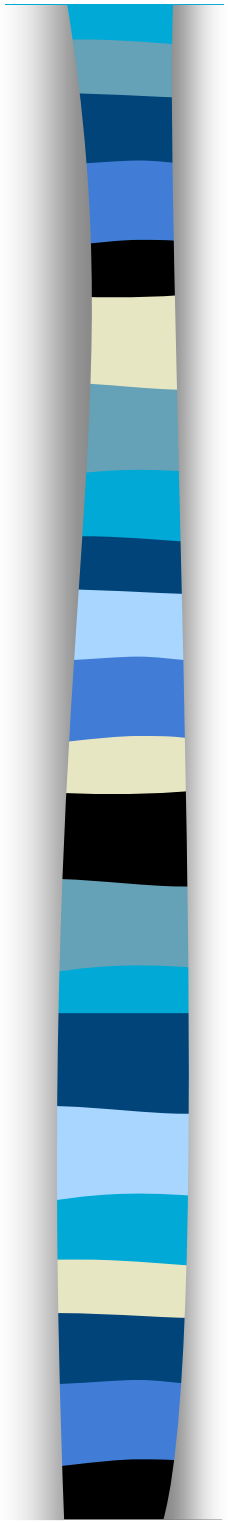
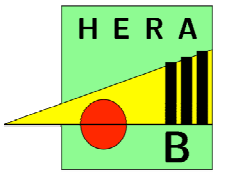
Outline of the Talk



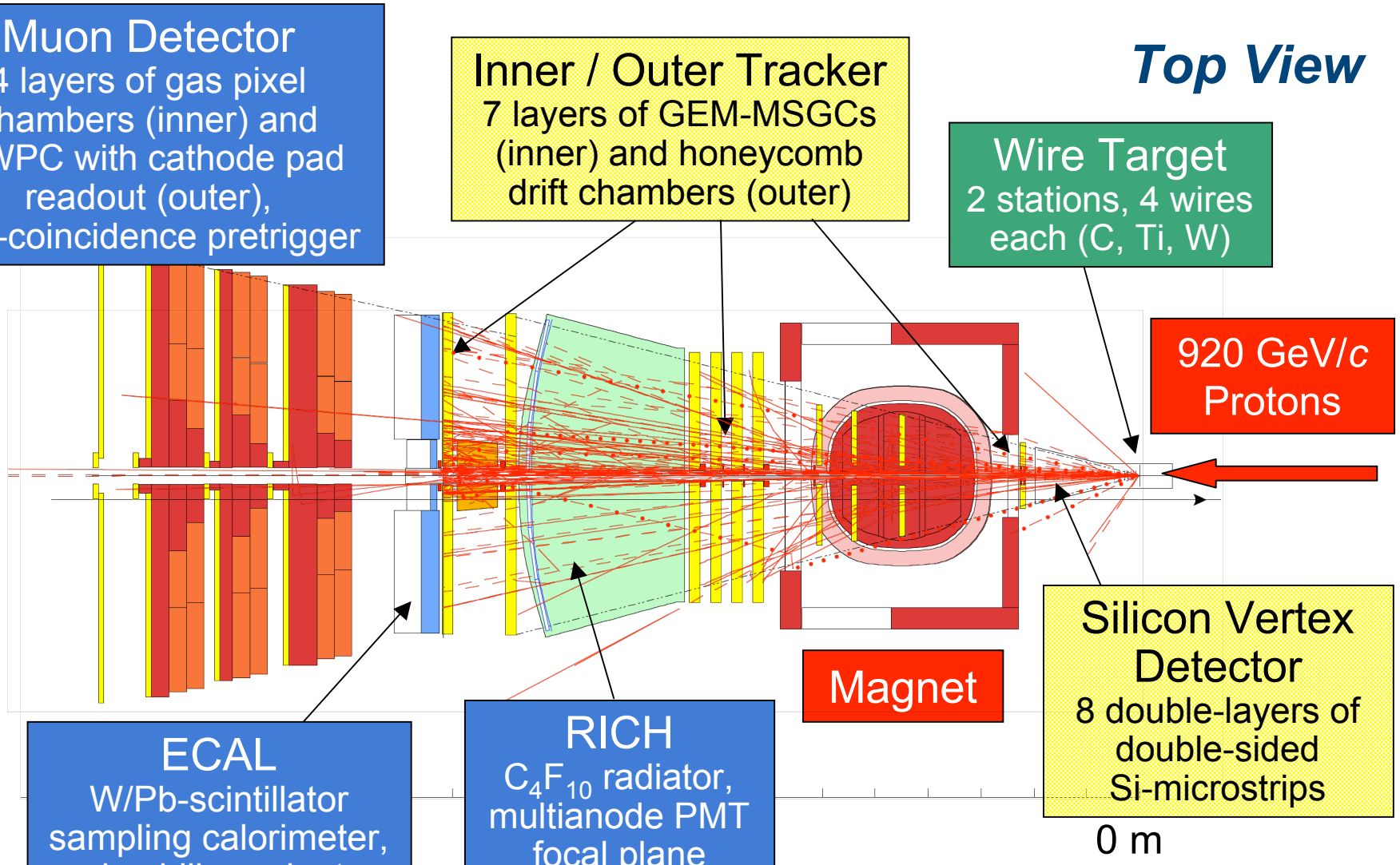
- HERA-B detector and trigger systems
- Charmonium production
- Open charm production
- Summary





Detector & Trigger

The HERA-B Detector



The Dilepton Trigger

HERA-B detector: data is read out and buffered for 10 μs
(proton bunches cross every 96 ns, 0.5 interactions/BX)

5 MHz

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

3 MHz

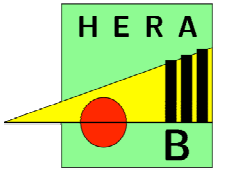
First Level Trigger (FLT): Track trigger in hardware using
tracking detectors behind magnet, seeding by pretriggers

20 kHz

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

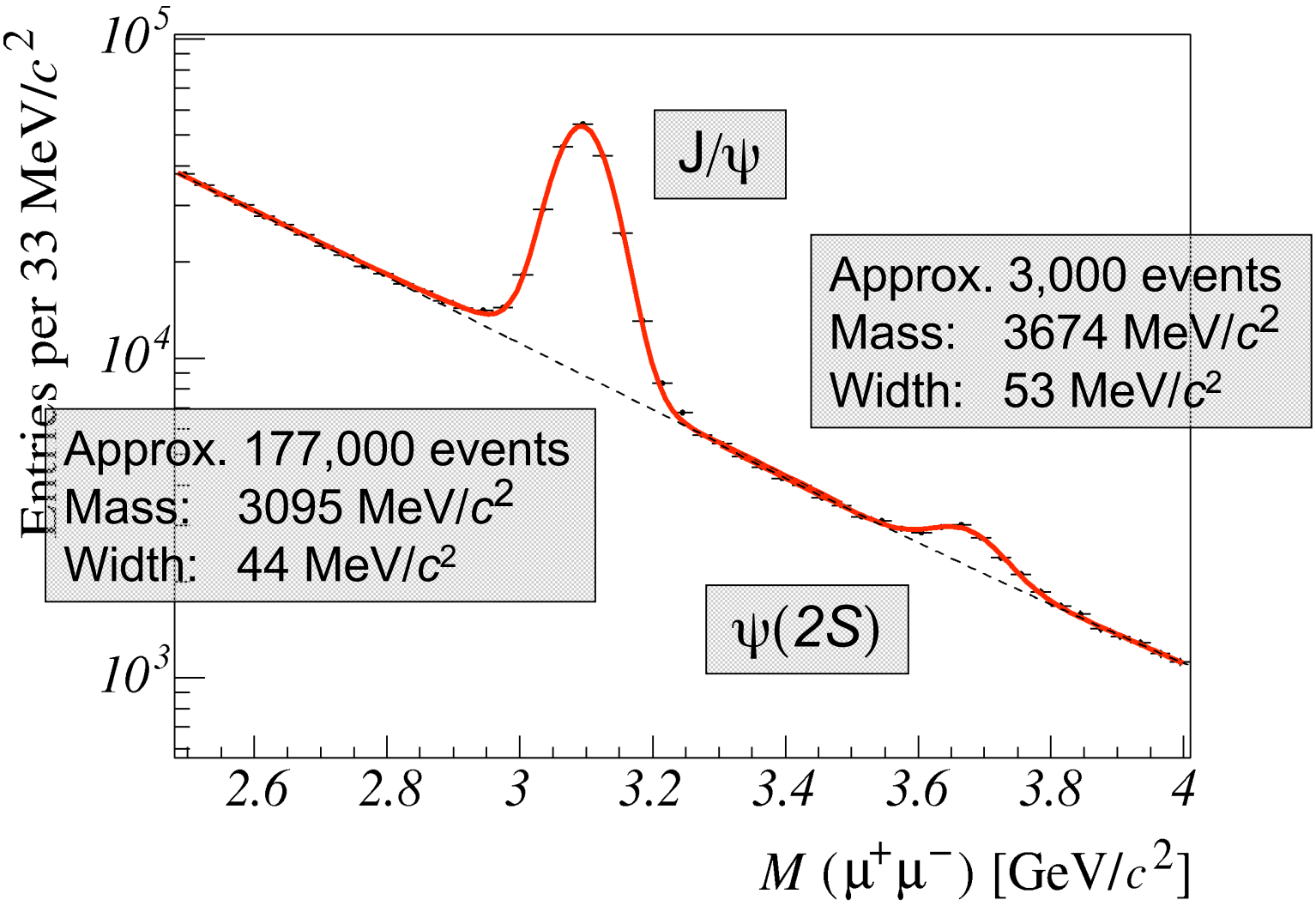
100 Hz

Data Sample 2002/2003

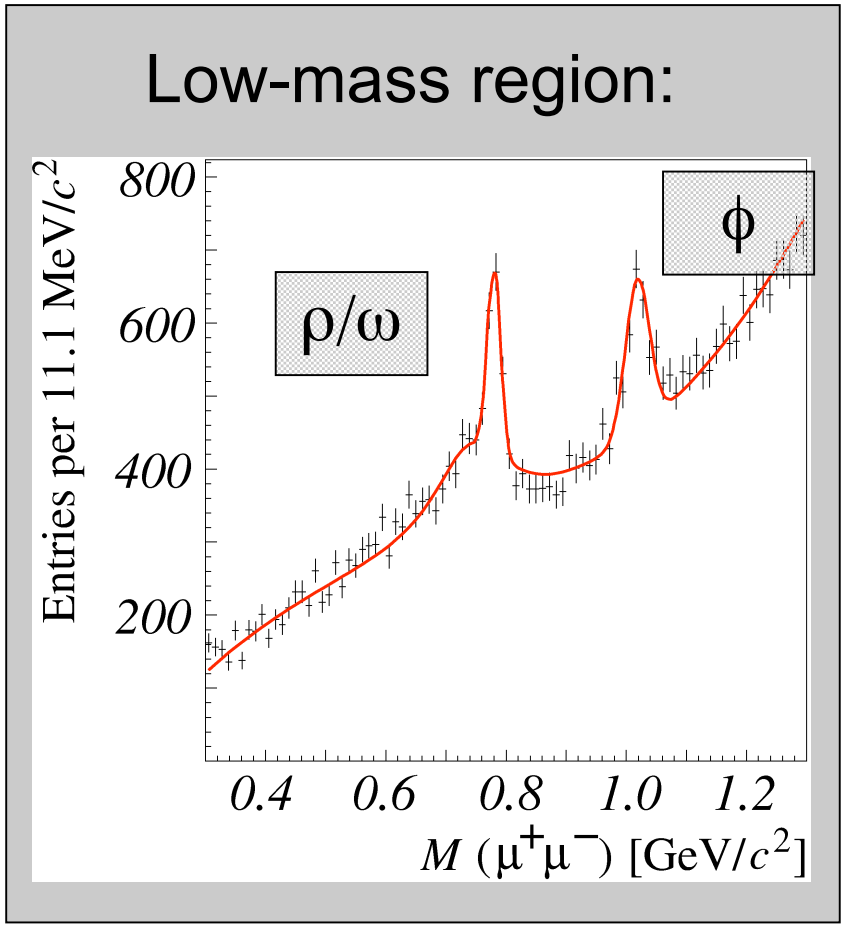


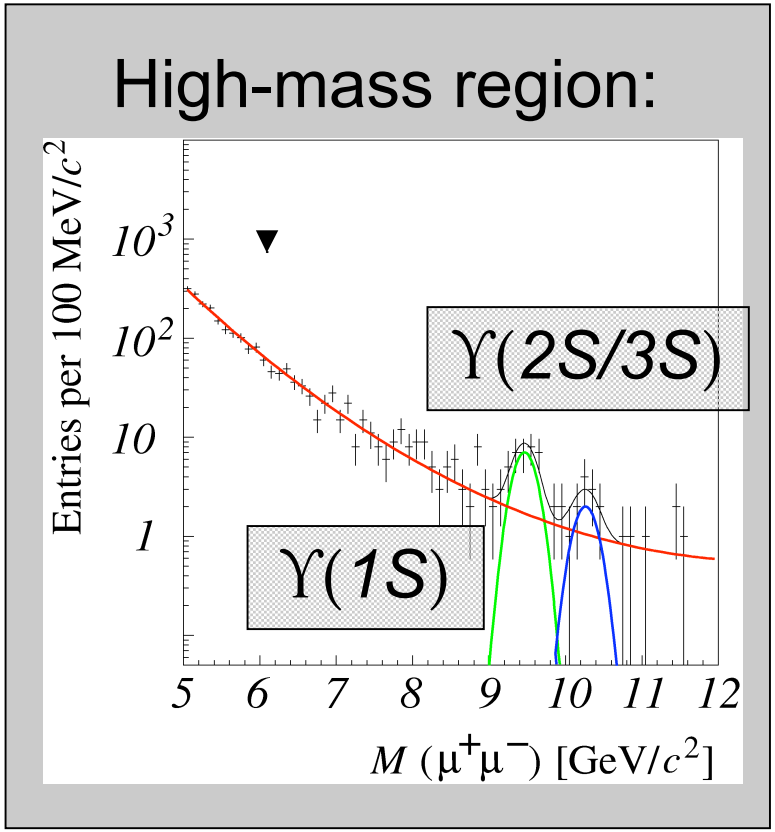
- Data-taking period: October 2002–February 2003
- Dilepton trigger: require ≥ 2 electrons or muons
  - Trigger performance: >1,000 J/ψ per hour
  - Sample for charmonium studies:
    - 300,000 J/ψ
    - 10,000 χ_c
    - 3,500 $\psi(2S)$
  - Study of beauty production → see talk by H. Wahlberg, B3.8
- Minimum bias trigger: minimum activity in RICH/ECAL
  - 200 million events recorded
  - Strangeness and hyperon production
  - Pentaquark searches → see talk by A. Sbrizzi, ST.3
  - Open charm production

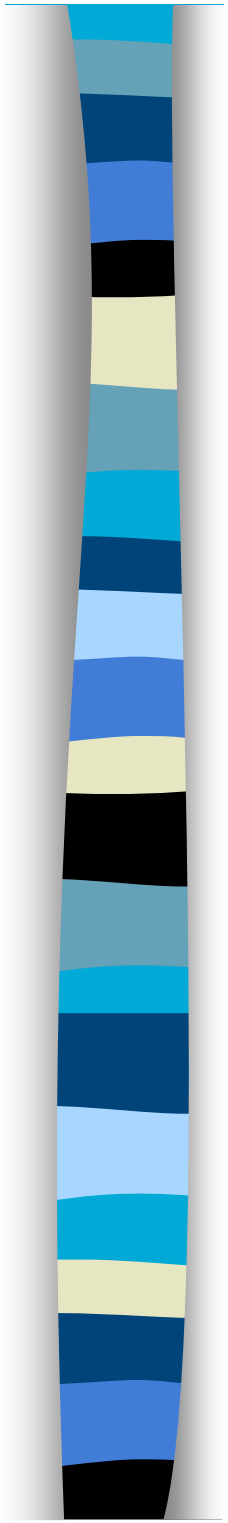
Dilepton Spectrum: Muon Channel

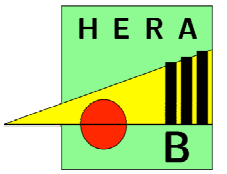


Dilepton Spectrum: Muon Channel





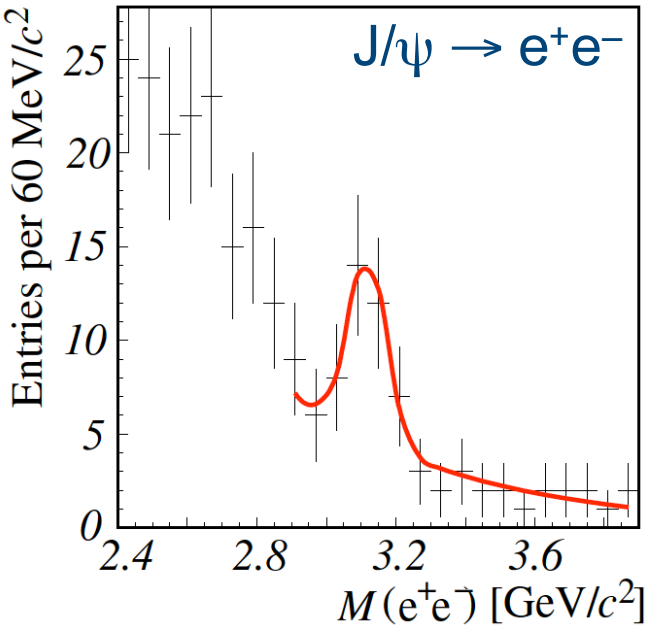


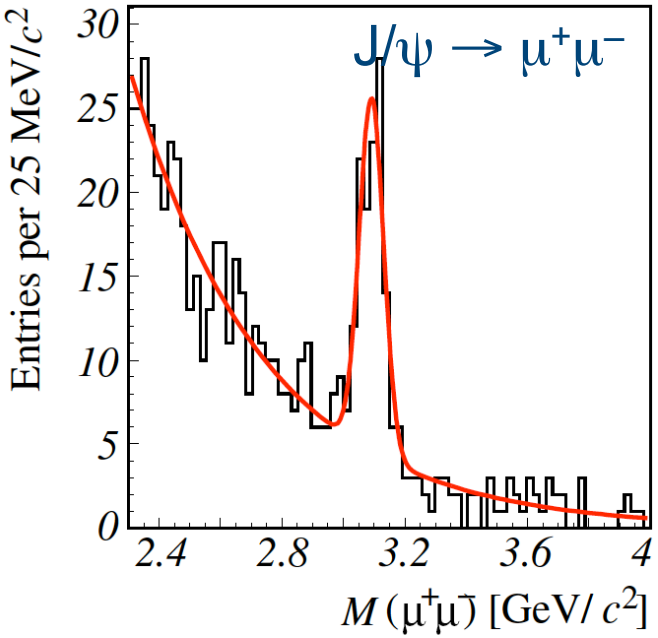


Charmonium Production

J/ψ Production Cross Section

- J/ψ → e^+e^- / $\mu^+\mu^-$ signals observed in minimum bias data



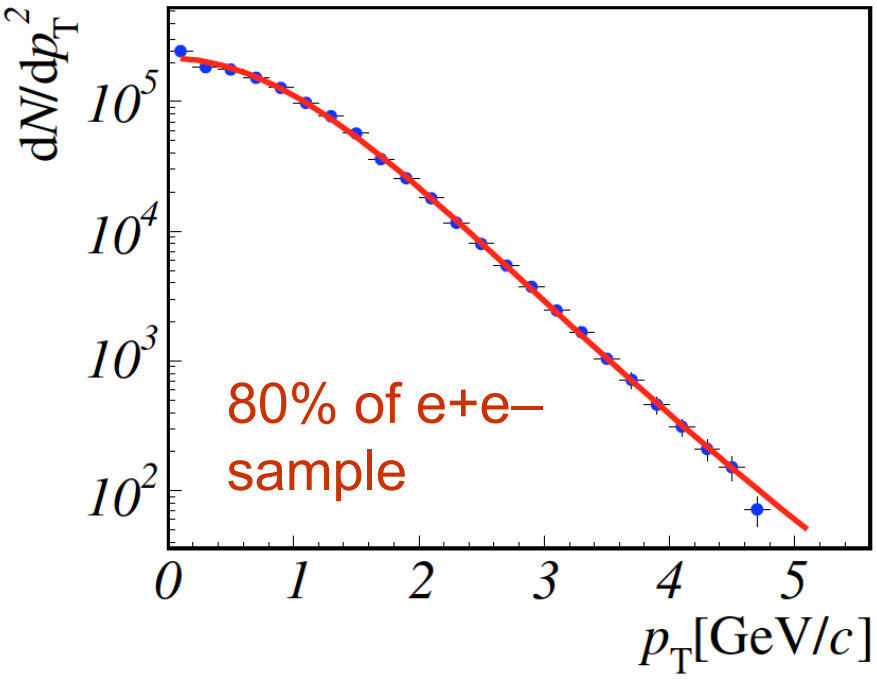


- Determination of J/ψ cross section without trigger bias

$$\sigma_0^{J/\psi} = \frac{N_{J/\psi}}{BR(J/\psi \to \ell^+\ell^-) \cdot \sum_i \varepsilon_i A_i^{\alpha} L_i}$$

(systematic effects currently under study)

J/ψ Differential Cross Section: p_T



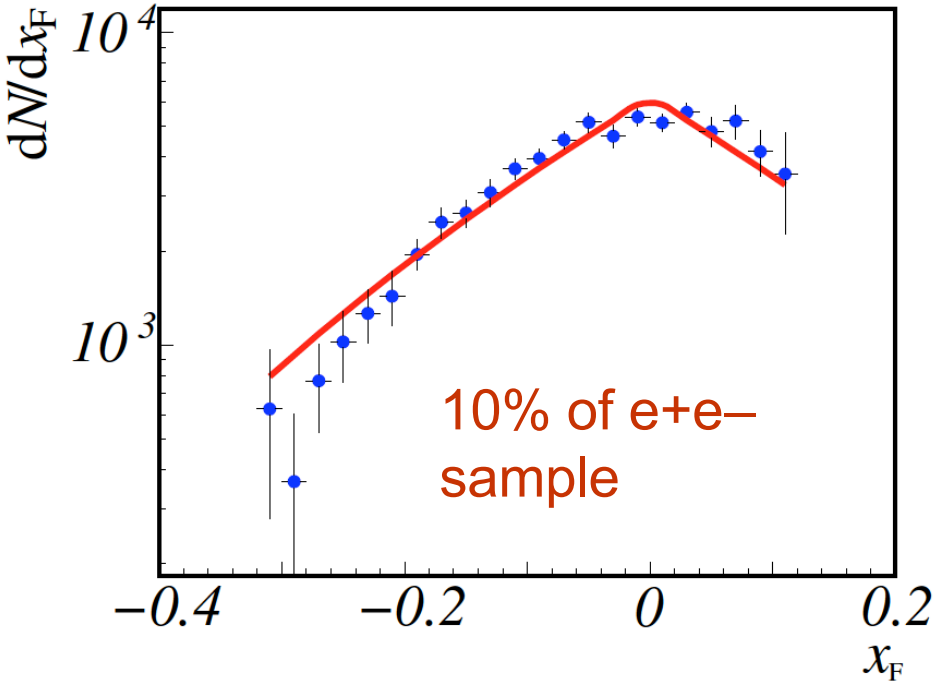
- Parametrization:

$$\frac{d\sigma}{dp_T} = A \cdot \left[1 + \left(\frac{35\pi \cdot p_T}{256\langle p_T \rangle}\right)^2\right]^{-6}$$

→ Broad p_T coverage, good agreement of electron and muon channel

Target	Experiment	p_T Range [GeV/c]	$\langle p_T \rangle$[GeV/c] e^+e^-	$\langle p_T \rangle$[GeV/c] $\mu^+\mu^-$
C, 920 GeV	HERA-B Preliminary	< 4.8	1.22 ± 0.01	1.22 ± 0.01
W, 920 GeV	HERA-B Preliminary	< 4.8	1.29 ± 0.01	1.30 ± 0.01
Si, 800 GeV	E771	< 3.5		1.20 ± 0.01
Au, 800 GeV	E789	< 2.6		1.290 ± 0.009

J/ψ Differential Cross Section: x_F



- Large acceptance for negative x_F (fractional longitudinal momentum)
- Parametrization:

$$\frac{d\sigma}{dx_F} = A \cdot \left(1 - |x_F|\right)^C$$

- Work on systematics ongoing

Target	Experiment	x_F Range	C
C, W, 920 GeV	HERA-B Preliminary	$-0.35 < x_F < 0.15$	$(5-6.5) \pm 0.3$
Si, 800 GeV	E771	$-0.05 < x_F < 0.25$	6.54 ± 0.23
Au, 800 GeV	E789	$-0.03 < x_F < 0.13$	4.91 ± 0.18
Cu, 800 GeV	E789	$0.30 < x_F < 0.95$	5.21 ± 0.04

J/ψ *A*-Dependence

- Test of charmonium production models in nuclear matter (nonrelativistic QCD + initial/final state interactions in nucleus)
- Parametrization: $\sigma_{pA} = \sigma_{pN} \cdot A^{\alpha}$, where $\sigma = N / \varepsilon L$
  - $\alpha < 1$: charmonium suppression by nuclear effects
  - HERA-B: extract α from runs with two target wires simultaneously (carbon: A=12, tungsten: A=184)

$$\alpha = \frac{1}{\log\left(A_W / A_C\right)} \log\left(\frac{N_W}{N_C} \cdot \frac{L_C}{L_W} \cdot \frac{\varepsilon_C}{\varepsilon_W} \right)$$

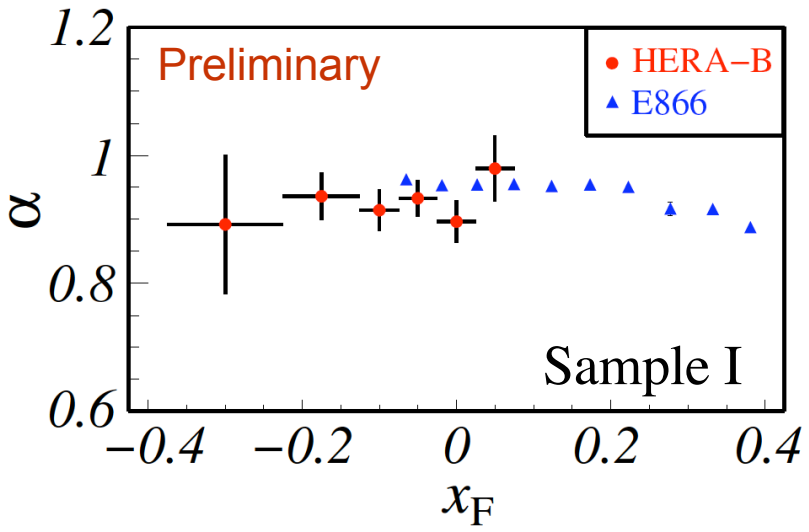
- 3 ingredients of A-dependence measurement:

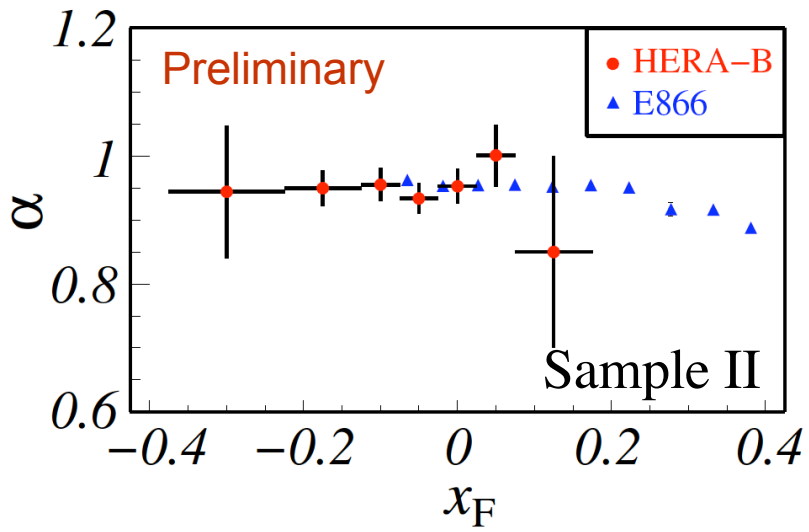
I. Ratio of J/ψ yields: fits to invariant mass spectra

II. Ratio of luminosities: intercalibration of target wires

III. Ratio of efficiencies: detailed detector/trigger simulation

J/ψ *A*-Dependence

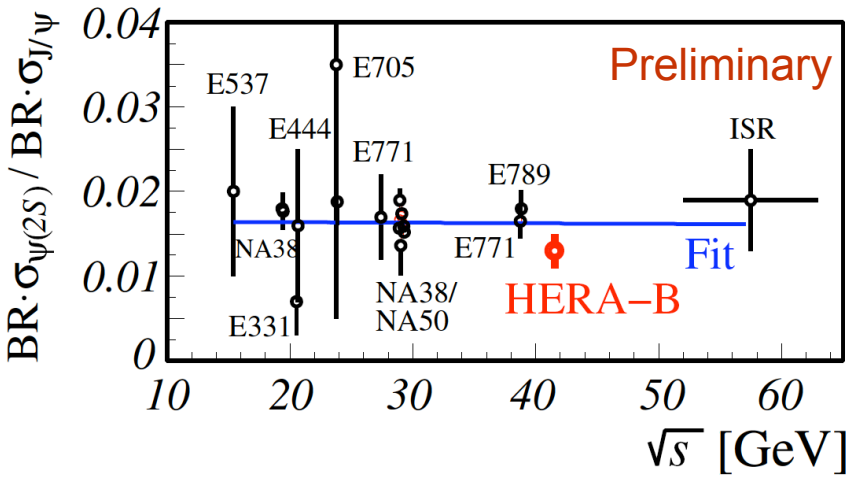


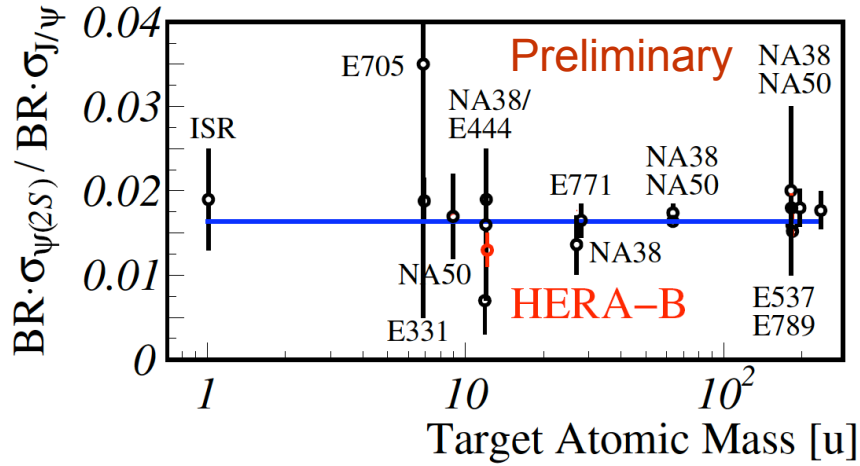


- Previous result of FNAL E866 extended to $x_F = -0.3$
- Result from 10% of full $\mu^+\mu^-$ sample, statistical uncertainties only
- Two different combinations of carbon and tungsten wires (different acceptances): consistent results
- Work on systematics ongoing

ψ(2S) Production

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





- Measure ψ(2S) cross section relative to J/ψ
  → reduce systematic uncertainties
- $\varepsilon_{J/\psi}/\varepsilon_{\psi(2S)} = 0.72$ (MC)
- Preliminary result (electrons, 30% of full statistics):

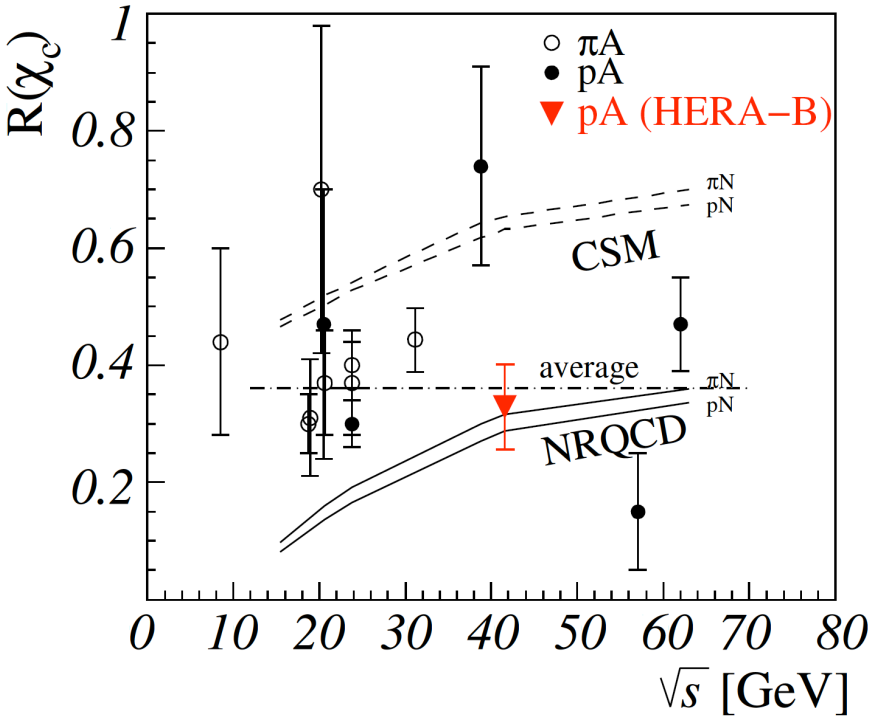
$$R = 0.13 \pm 0.02 \text{ (stat.)}$$

- Muon channel: compatible results

χ_c Production

- Test of charmonium production models: fraction $R(\chi_c)$ of J/ψ from radiative decays $\chi_c \rightarrow$ J/ψ $\gamma \rightarrow \mu^+ \mu^- \gamma$

$$R(\chi_c) = \frac{\sum_{i=1}^{2} \sigma_{\chi_{c,i}} \cdot \mathrm{BR}(\chi_{c,i} \rightarrow \mathrm{J}/\psi\gamma)}{\sigma_{\mathrm{J}/\psi}} = \frac{N_{\chi_c}}{N_{\mathrm{J}/\psi}} \cdot \frac{\varepsilon_{\mathrm{J}/\psi}}{\varepsilon_{\chi_c}\varepsilon_{\gamma}}$$



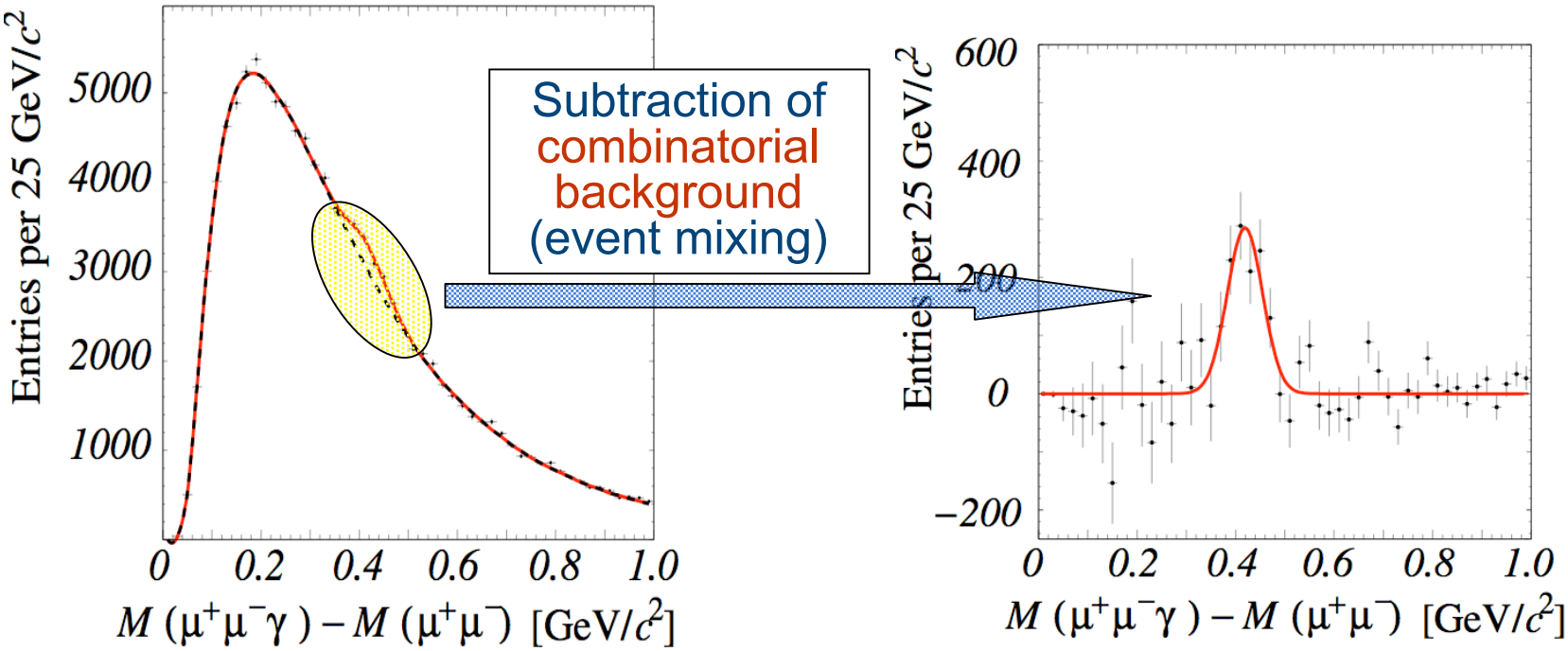
Published result of 2000 data-taking (370±74 χ_c):

$R(\chi_c)$=0.32
±0.06(stat.)±0.04(syst.)

I. Abt *et al.*, Phys. Lett. **B561** (2003) 61

R(χ_c): Analysis in 2002/2003

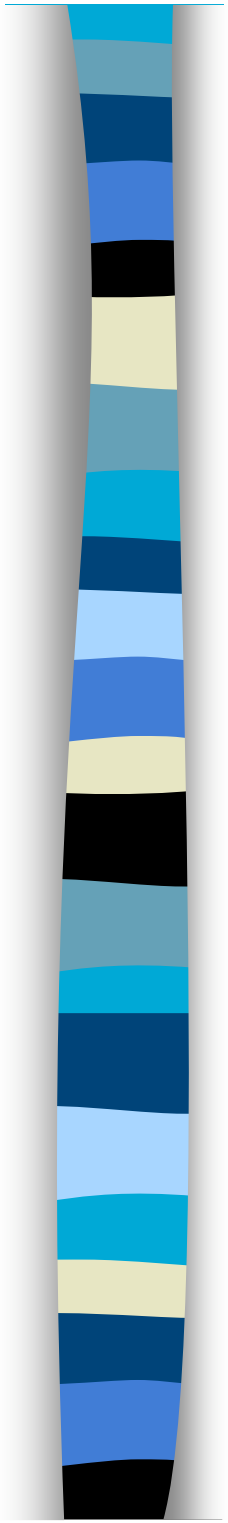
- Signal found in mass difference $M(J/\psi\,\gamma) - M(J/\psi)$

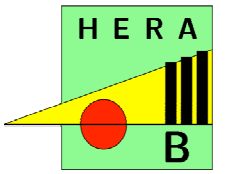


- Preliminary result (15% of $\mu^+\mu^-$ statistics, 1,300 χ_c):

$$R(\chi_c) = 0.21 \pm 0.05(\text{stat.})$$

→ compatible with 2000 results, systematic studies ongoing



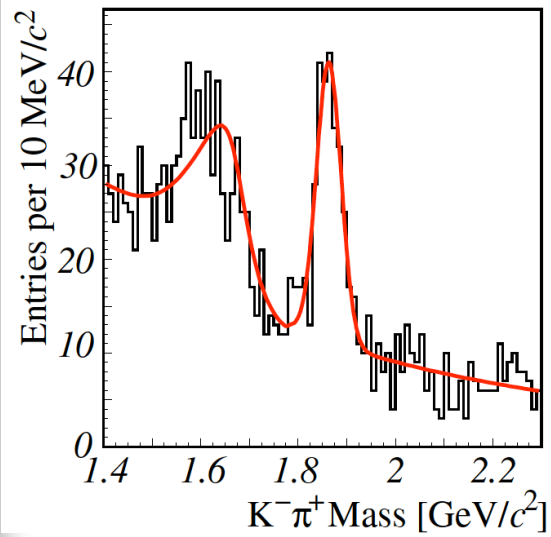


Open Charm Production

Open Charm Production

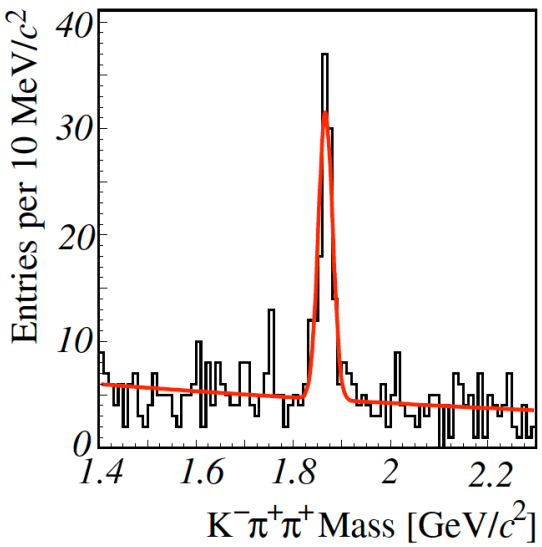
Open charm signals in minimum bias data (charge-conjugated channels included):

$D^0 \rightarrow K^- \pi^+$



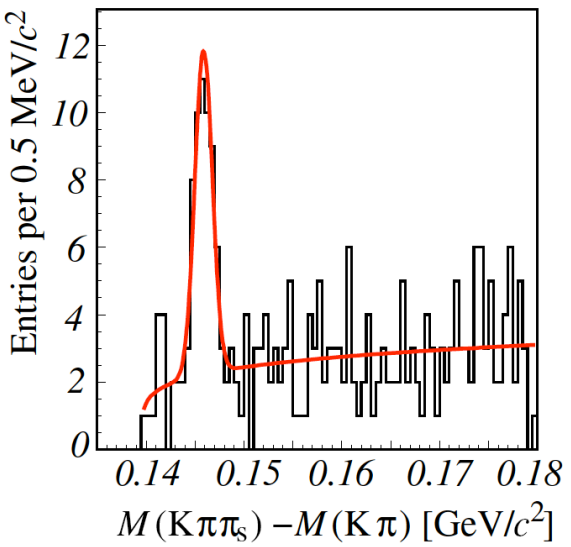
Events:	189 ± 20
M [MeV/c^2]:	1863 ± 3
σ [MeV/c^2]:	25 ± 3

$D^+ \rightarrow K^- \pi^+ \pi^+$



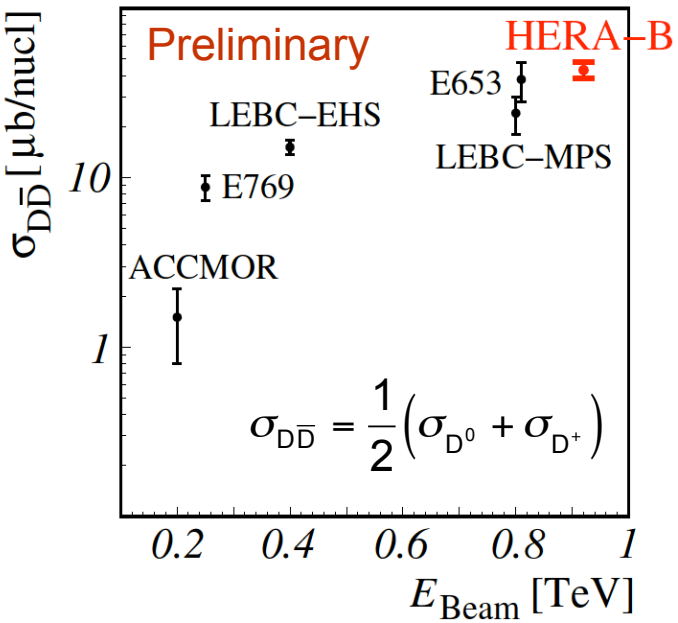
Events:	98 ±12
M [MeV/c^2]:	1866 ± 2
σ [MeV/c^2]:	15 ± 2

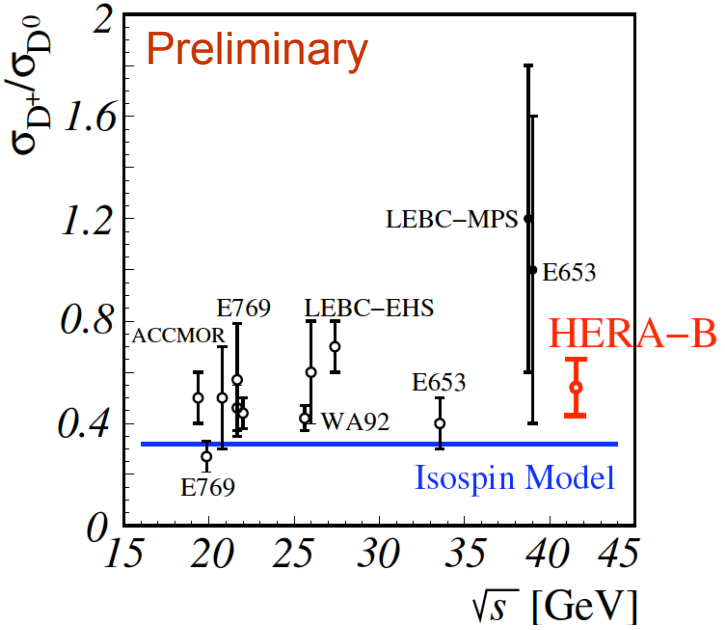
$D^{*+} \rightarrow D^0 \pi^+ \rightarrow K^- \pi^+ \pi^+$



Events:	43 ± 8
ΔM [MeV/c^2]:	145.9 ± 0.2
σ [MeV/c^2]:	0.89 ± 0.15

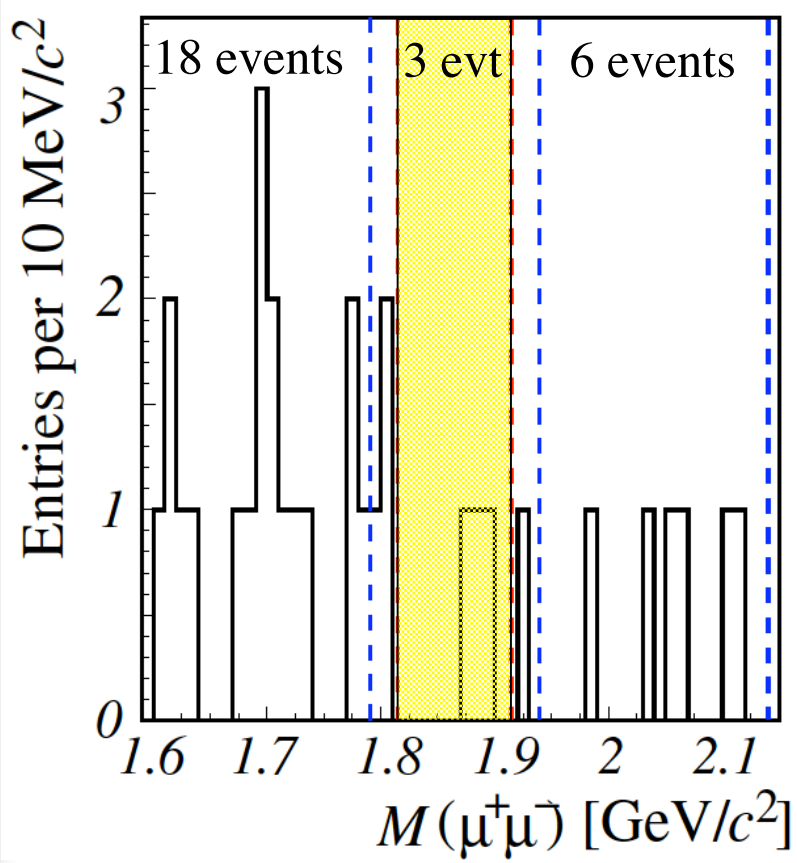
Open Charm Production





Preliminary	$-0.1 < x_F < 0.05$	full x_F range
σ_{D^0} [μb/nucl]	$21.4 \pm 3.2 \pm 3.6$	$56.3 \pm 8.5 \pm 9.5$
σ_{D^+} [μb/nucl]	$11.5 \pm 1.7 \pm 2.2$	$30.2 \pm 4.5 \pm 5.8$
$\sigma_{D^{*+}}$ [μb/nucl]	$10.0 \pm 1.9 \pm 1.4$	$27.8 \pm 5.2 \pm 3.9$
Ratio $\sigma_{D^+}/\sigma_{D^0}$		$0.54 \pm 0.11 \pm 0.14$
Ratio $\sigma_{D^{*+}}/\sigma_{D^0}$		$0.49 \pm 0.12 \pm 0.10$

New Limit on BR($D^0 \to \mu^+\mu^-$)



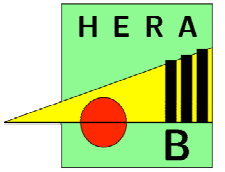
- Search for flavor-changing neutral current decay $D^0 \to \mu^+\mu^-$ (branching fraction enhanced in some SUSY models)
- 3 events in signal region:

$$BR(D^0 \to \mu^+\mu^-) < 2.0 \times 10^{-6} \ (90\%\ CL)$$

Currently best upper limit
I. Abt *et al.*, hep-ex/0405059,
to be published in Phys. Lett. **B**

- Previous limit by CDF:
$BR(D^0 \to \mu^+\mu^-) < 2.5 \times 10^{-6}$ (90% CL)
D. Acosta *et al.*,
Phys. Rev. **D68** (2003) 091101

Summary & Outlook



- HERA-B has finished data-taking
- Analysis of 2002/2003 data in progress
- Charmonium production:
  - Production cross sections and differential distributions
  - *A*-dependence of J/ψ production: HERA-B covers $x_F<0$
  - Production ratios: ψ(2*S*) to J/ψ, fraction of J/ψ from χ_c
- Open charm production:
  - D meson production cross sections and ratios: D^0, $D^{\pm}$, $D^{*\pm}$
  - New limit for FCNC decay: $D^0 \rightarrow \mu^+\mu^-$
- Outlook:
  - First results of 2002/2003 run to be published soon
  - Stay tuned – more interesting results to come

Thanks to: HERA-B charmonium & open charm working groups