Experimental Review on Quarkonium

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XVIII RENCONTRES DE PHYSIQUE DE LA VALLEE D'AOSTE

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E866/NuSea

- Introduction
- TEVATRON - $p\bar{p}$ - (Production and Spectroscopy)
  - Collider and fixed target
- LEP - e^+e^- - (Production)
- HERA - $e^{\pm}p$ - (Production)
  - Collider and fixed target

(Inelastic production measurements)

- KEKB-PEPII - e^+e^- - (Production and Spectroscopy)
- Conclusions

J/ψ
$\psi(2S)$
χ_c
Υ
χ_b
η_b
X(3872)

Introduction – Heavy Quarkonium

Privileged window into the QCD world.

Multi-scale systems probing all energy regimes of QCD

Renewed interest, puzzles, challenges, discovery of new states.

Many running experiments cross checking each other (e^+e^- machines, ep machines, ppbar machines) and challenging theory. Getting information from photon-photon fusion, photon-gluon fusion, gluon-gluon fusion, etc.). Answers and more challenges are around the corner.

Various theoretical approaches have matured and can cross check each other.

Tevatron Performance

- ***Tevatron (Run I 1992-96, ∫L dt = 110 pb^{-1}):***
  - ***p → ← pbar at √s = 1.8 TeV, 3.5 μs between collisions***
- ***Tevatron (Run II 2002-Present, ∫L dt = ~430 pb^{-1}):***
  - ***p → ← pbar at √s = 1.96 TeV, 396 ns between collisions***

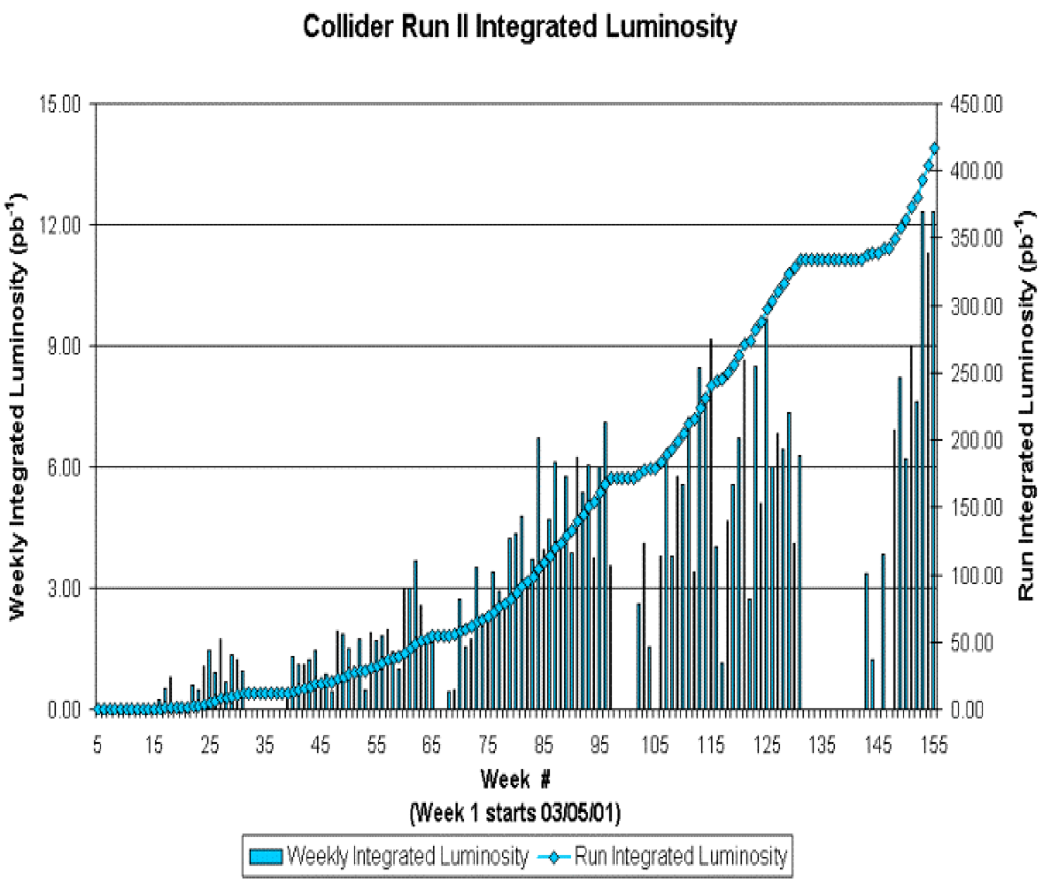
Stores 3245, 3261

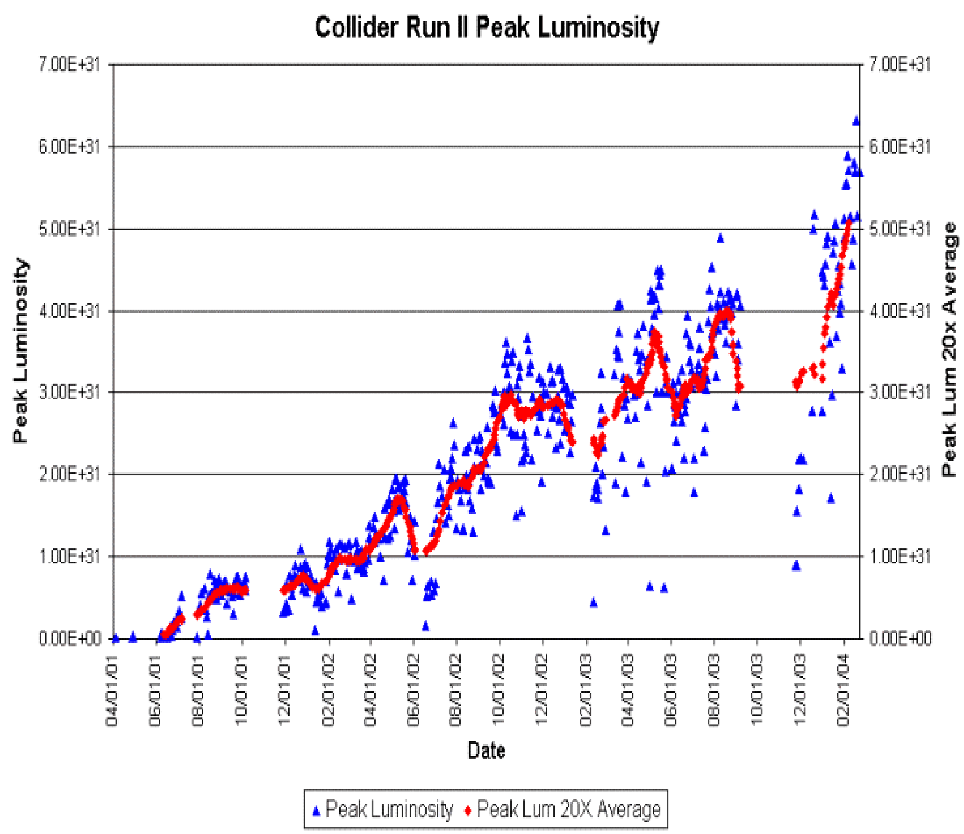
02/18/04, 02/27/04

6.26, 6.75 x 10^{31} cm^{-2}s^{-1}

Duration of 35.3, 41.0 hours

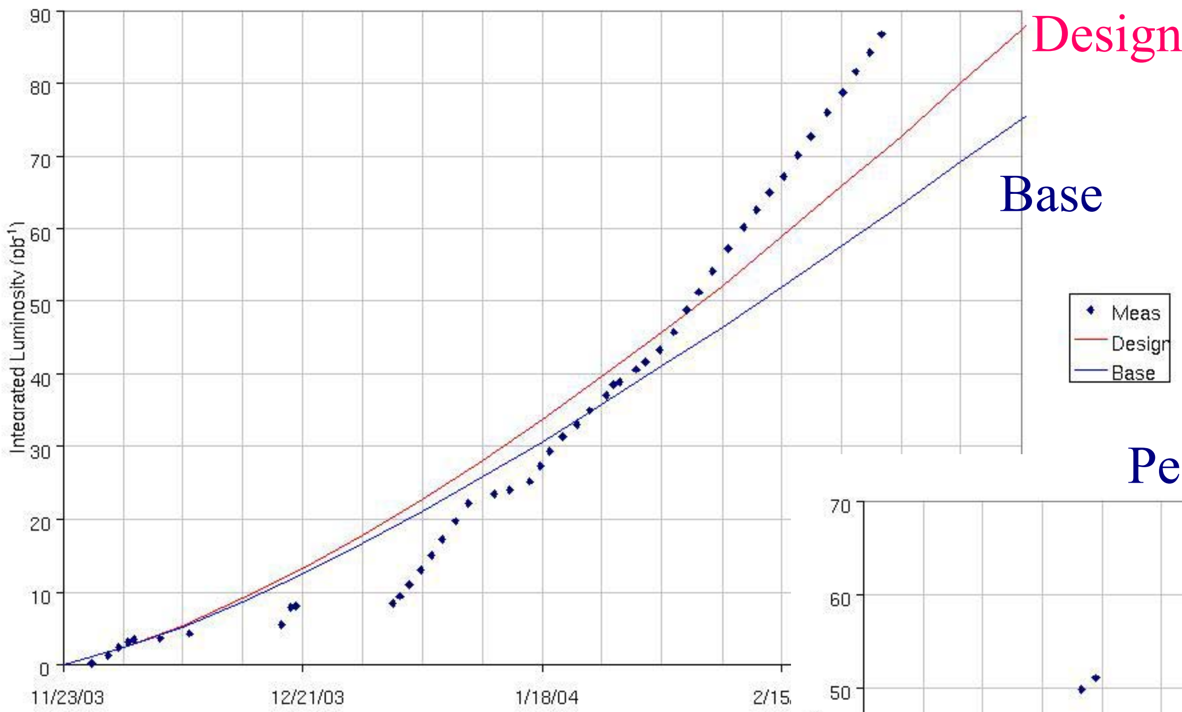
3.19, 3.94 pb^{-1} per experiment



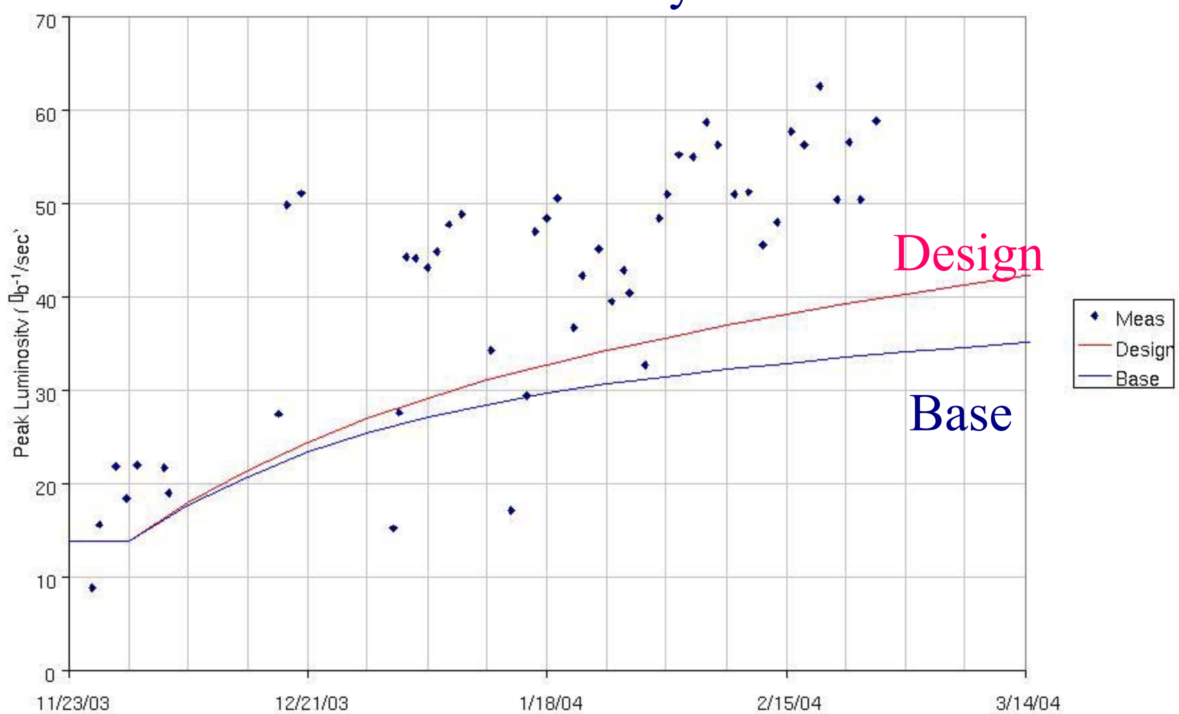


Tevatron Performance

Integrated Luminosity since 11/23/03



Peak Luminosity since 11/23/03



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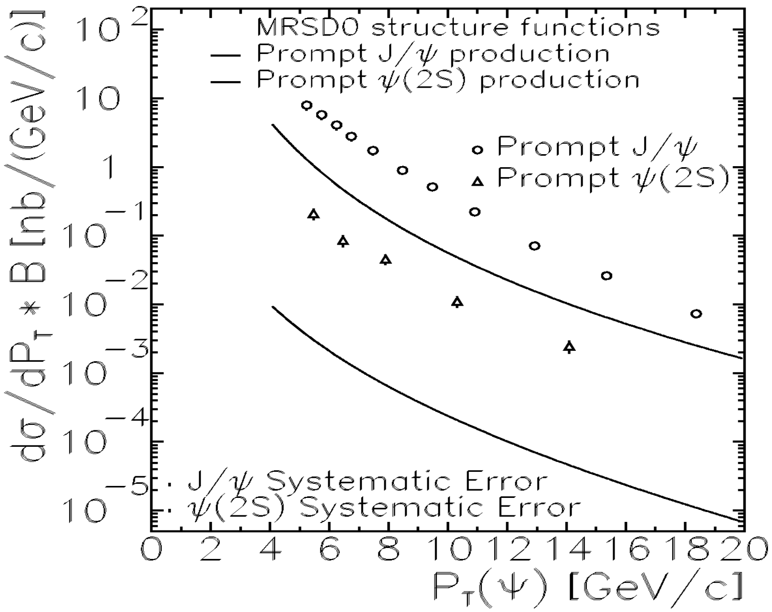
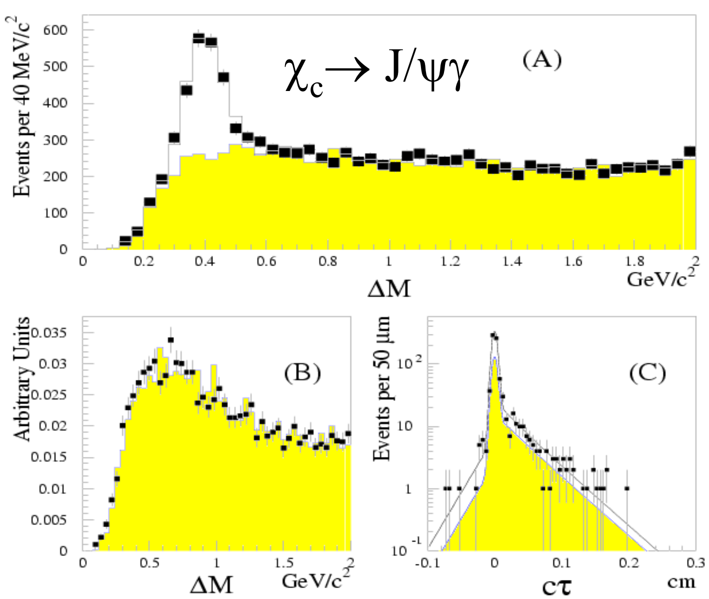
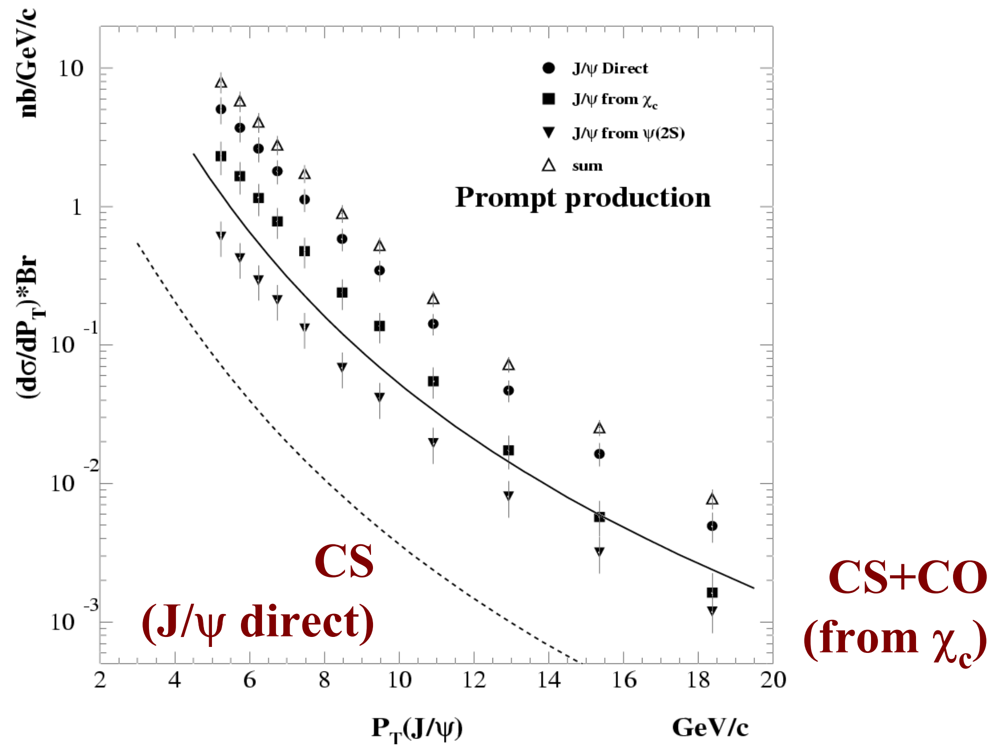
Prompt / Direct J/ψ Cross Section - CDF



J/ψ , $\psi(2S) \rightarrow \mu\mu$

- Prompt J/ψ cross section includes
  - χ_c decays ($\chi_c \rightarrow J/\psi\gamma$ measured)
  - ψ(2S) feed-down (measured)
  - Direct J/ψ (64±6%)





CDF, PRL 79(1997) 572, 578

Direct $\psi(2S)$ Cross Section - CDF

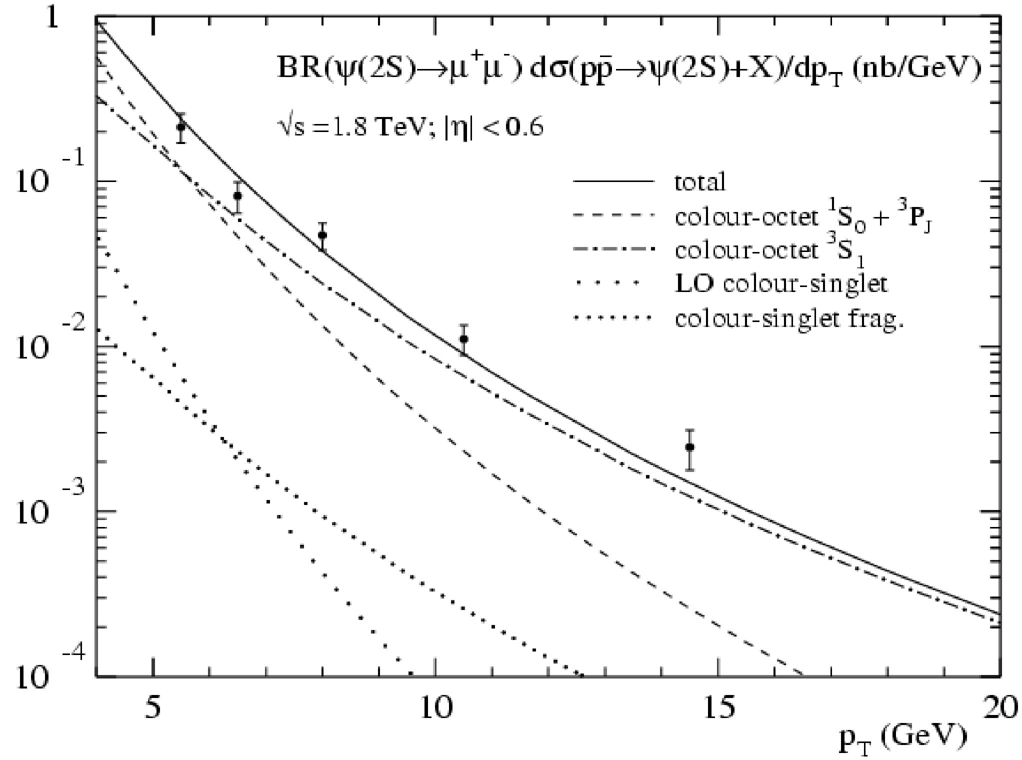
- $\psi(2S) \rightarrow \mu\mu$, Run IA data, 18 pb^{-1}
- "Central muons" ($|\eta| < 0.6$)
- Lifetime information used to extract prompt component
- *Prompt* $\equiv$ *direct* for $\psi(2S)$
- Colour singlet fusion: α_S^3/p_T^8
- CS fragmentation (Braaten, Yuan, PRL 71(1993) 1673): α_S^5/p_T^4

$$g^* \rightarrow 2g + c\bar{c}(^3S_1^{(1)}) \rightarrow \psi(2S)$$

- NRQCD expansion

$$d\sigma(H) = \Sigma_n d\sigma[c\bar{c}(n)]\langle O^H(n)\rangle$$

  - n includes colour singlet and octet states
  - Expansion in α_s and v (relative velocity of quark and anti-quark)



Beneke, Krämer, PRD 55(1997) 5269

CDF Data: PRL 79(1997) 572

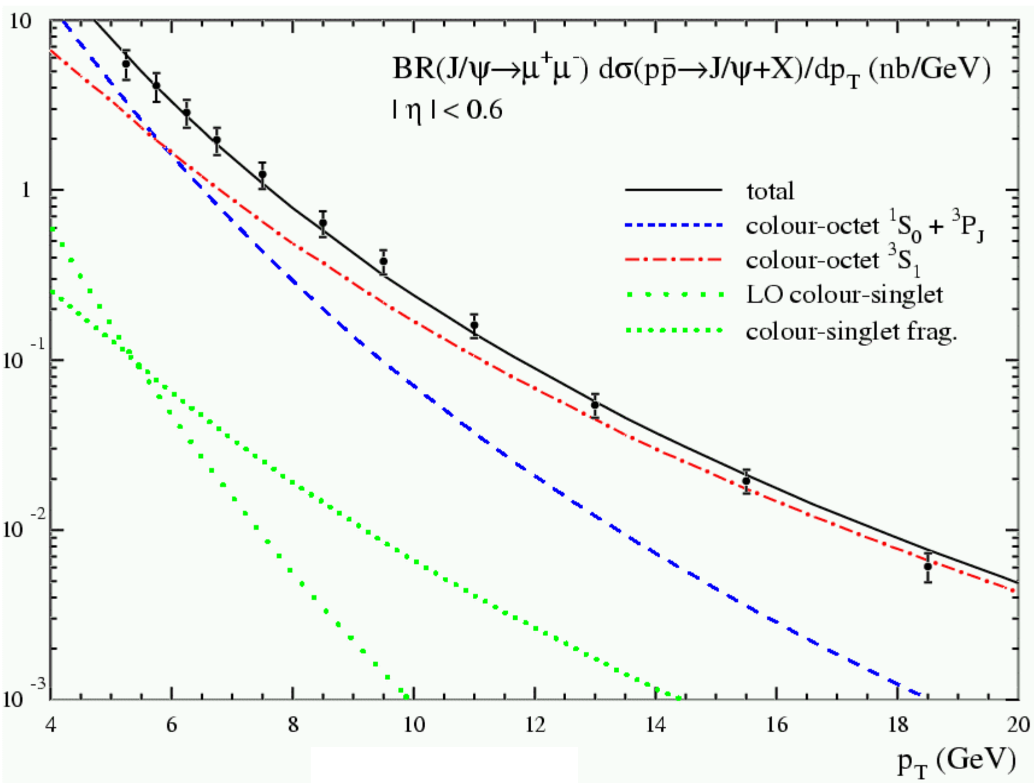
- Colour octet fragmentation (Braaten, Fleming, PRL 74(1995) 3327): $\alpha_S^3 v^4/p_T^4$

$$g^* \rightarrow c\bar{c}(^3S_1^{(8)}) \rightarrow \psi(2S)$$

- *Fragmentation dominates at high* p_T

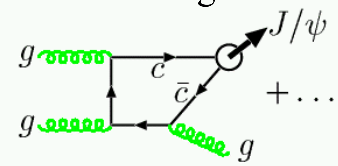
Direct J/ψ Cross Section - CDF

- Large uncertainties in the extracted matrix elements
  - low p_T: effects of gluon k_t
  - parton density functions



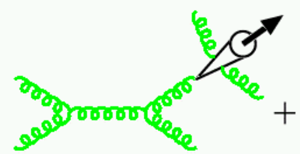
Beneke, Krämer, PRD 55(1997) 5269

LO colour singlet:



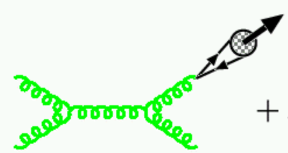
$+\ldots \qquad \sim \alpha_s^3 \frac{(2m_c)^4}{p_t^8}$

colour-singlet fragmentation: $g+g \to [c\bar{c}[^3S_1^{(1)}]+gg]+g$



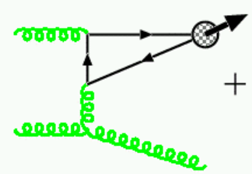
$+\ldots \qquad \sim \alpha_s^5 \frac{1}{p_t^4}$

colour-octet fragmentation: $g+g \to c\bar{c}[^3S_1^{(8)}]+g$



$+\ldots \qquad \sim \alpha_s^3 \frac{1}{p_t^4} v^4$

colour-octet fusion: $g+g \to c\bar{c}[^1S_0^{(8)}, {}^3P_J^{(8)}]+g$



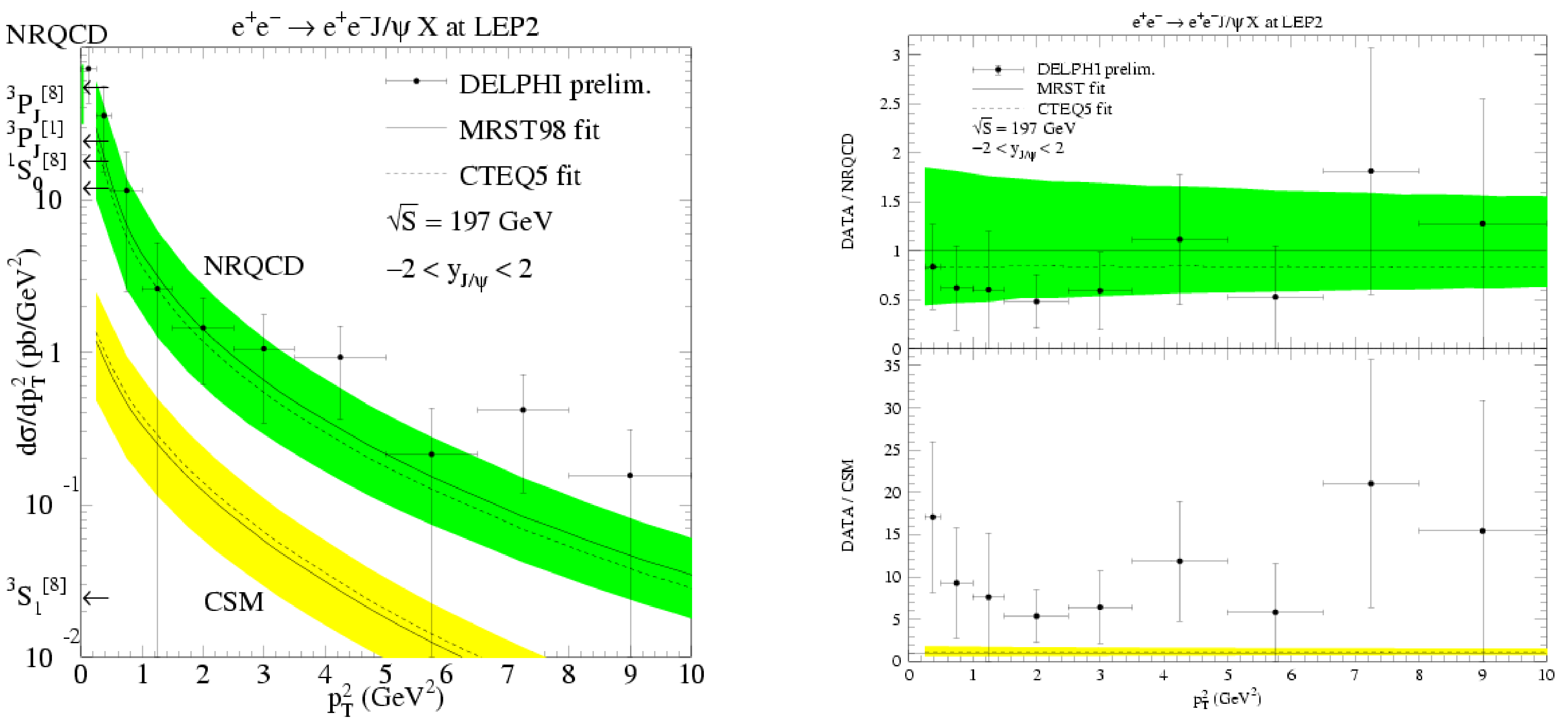
$+\ldots \qquad \sim \alpha_s^3 \frac{(2m_c)^2}{p_t^6} v^4$

LEP2 - DELPHI

- **Photoproduction ($\gamma\gamma \to J/\psi X$) at LEP** 617 pb^{-1} PL B565(2003) 76

Comparison of theory with data clearly favors NRQCD over CSM.

Theory uncertainties mainly from CO ME and renormalization/factorization scales.



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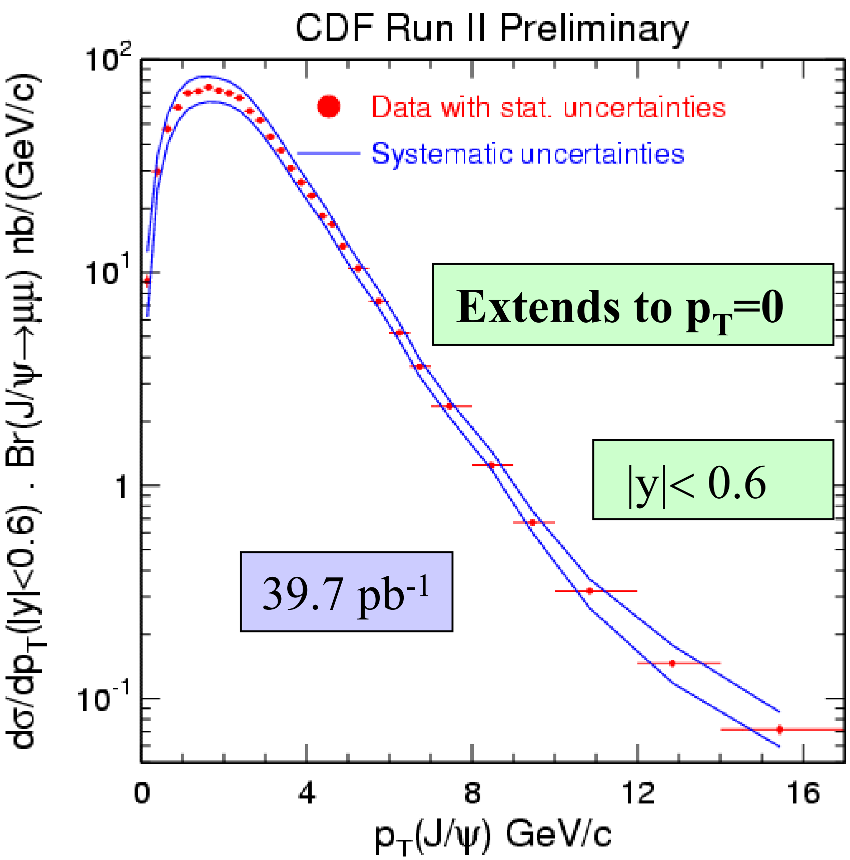
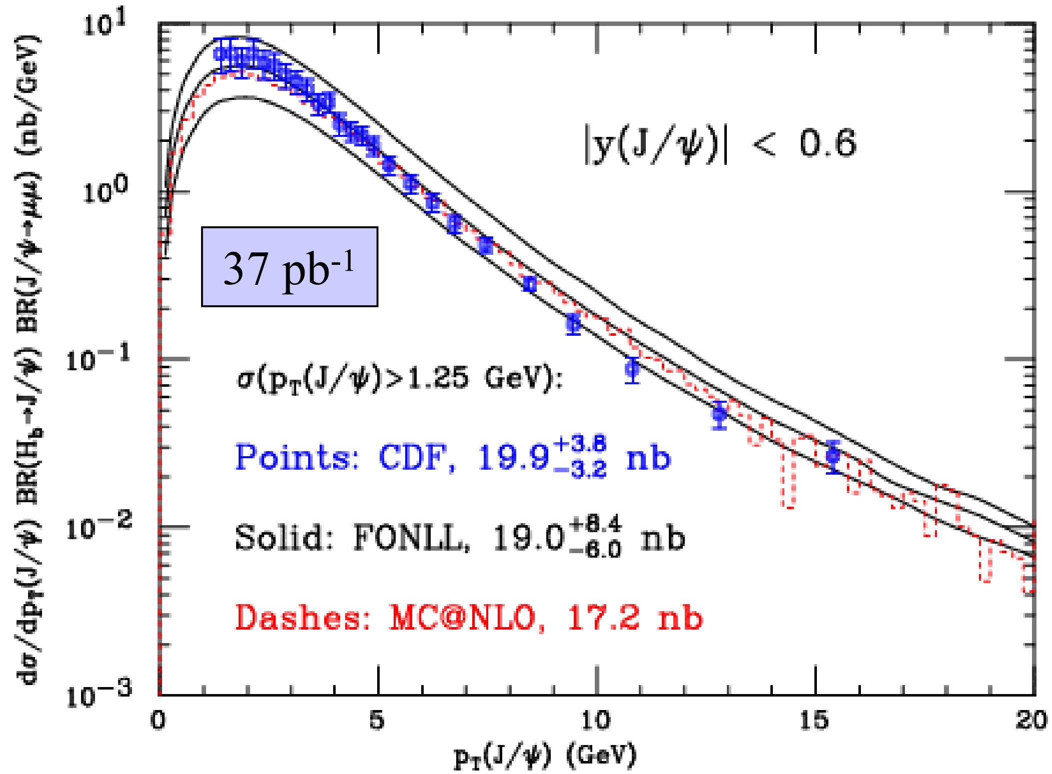
Klasen, Kniehl, Mihaila, Steinhauser PRL 89(2002) 032001

J/ψ Cross Section – Run II (CDF)





Cacciari, Frixione, Mangano, Nason, Ridolfi, hep-ph/0312132

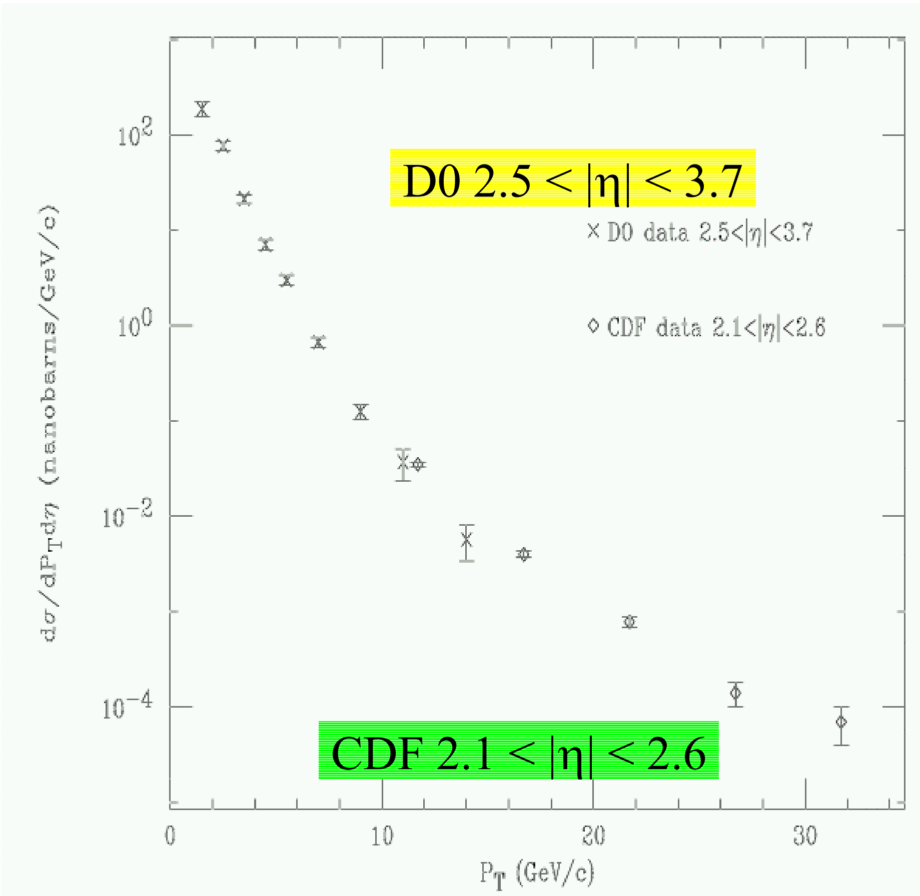
$$\sigma_{p\bar{p}\to J/\psi} = 240 \pm 1(stat)^{+35}_{-28}(syst)nb$$

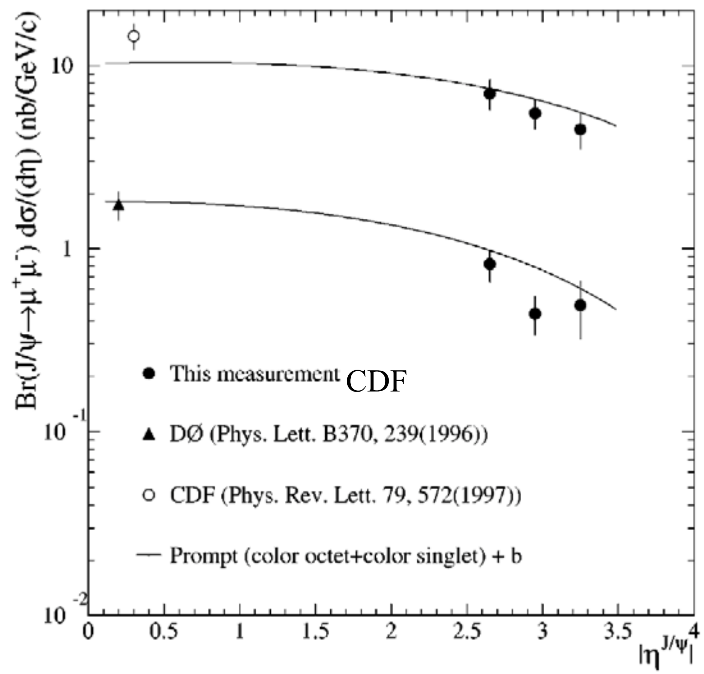
$$\sigma(p\bar{p} \to H_b X, |y| < 0.6) Br(H_b \to J/\psi X) Br(J/\psi \to \mu\mu) =$$

$$24.5 \pm 0.5(\text{stat}) \pm 4.7(\text{syst})\text{nb}$$

Central-Forward J/ψ Production (CDF/D0)

CDF: PRD 66(2002)092001
D0: PRL 82(1999)35





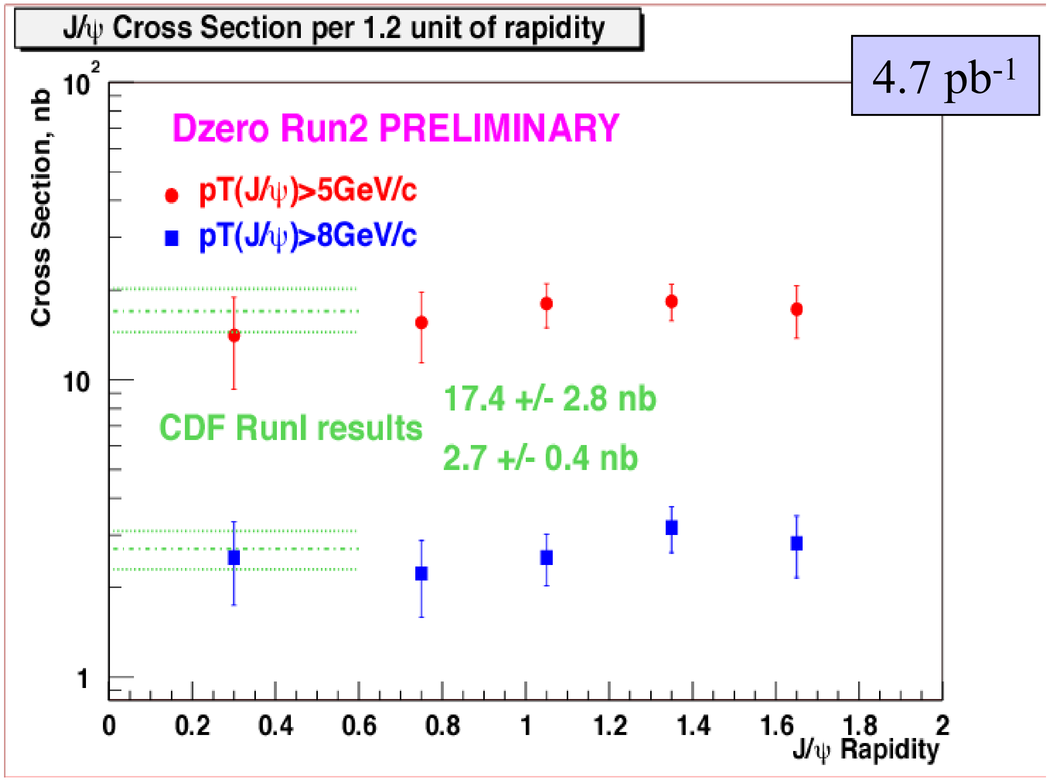
p_T>5GeV

p_T>8GeV

Reasonable agreement between central and forward measurements

CDF Run II: low p_T muon coverage (|η|<1.5)

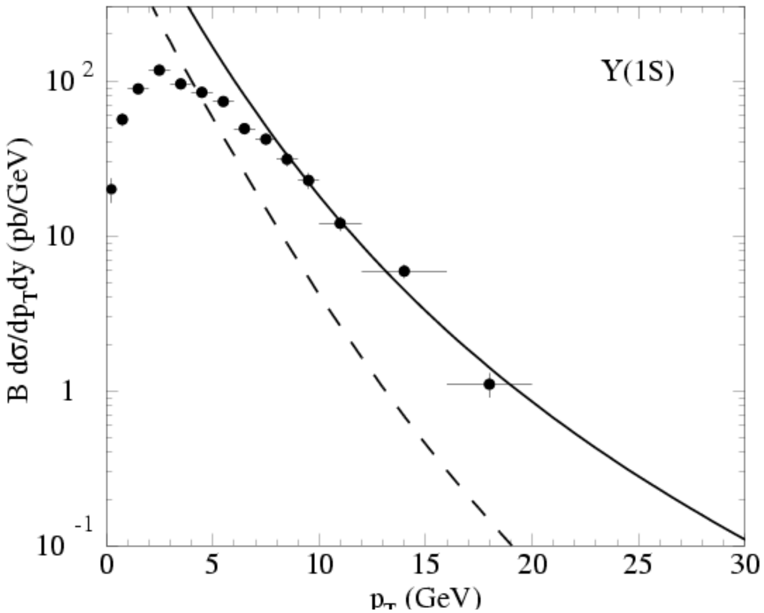
J/ψ Cross Section - Run II

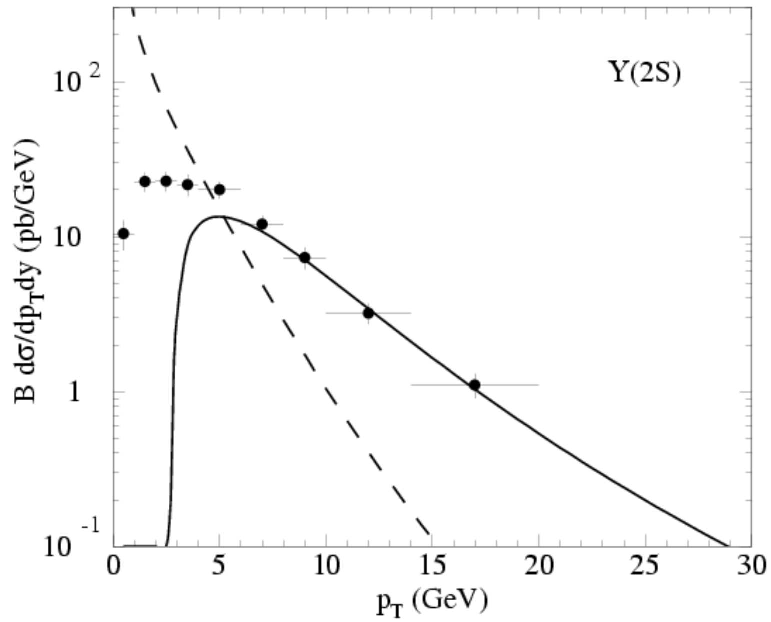


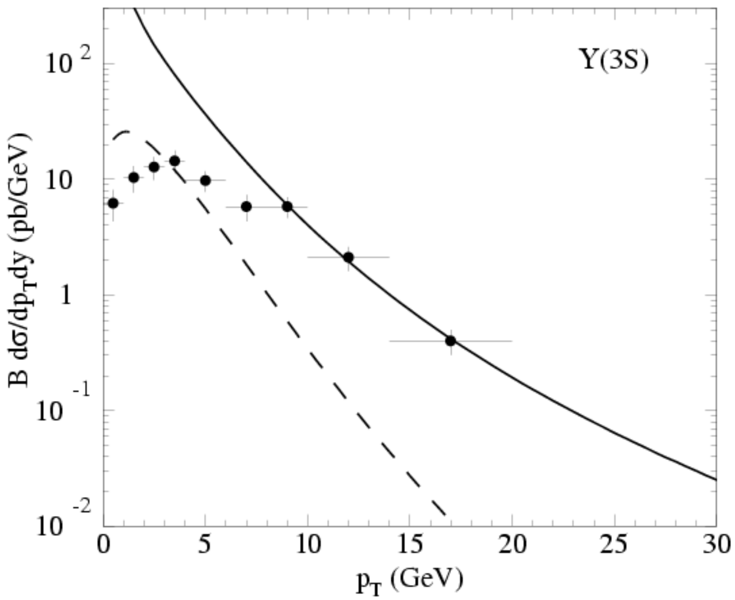
Cross section as a function of rapidity

ϒ Cross Section at CDF

Run I:
PRL 88 (2002)161802



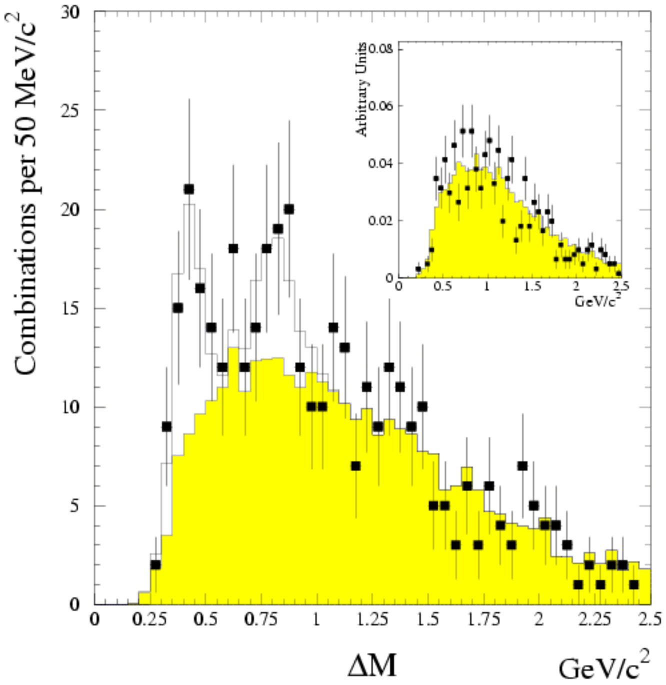




- smaller discrepancy with CSM but similar to $c\bar{c}$ result
- NRQCD CS+CO terms able to fit data with $p_T > 8$ GeV/c

χ_b Feed-down to $\Upsilon(1S)$ at CDF

Run I:
PRL 84 (2000) 2094



- $\chi_b(1P, 2P) \rightarrow \Upsilon(1S)\gamma$
- $p_T(\Upsilon) > 8$ GeV/c
- γ backgrounds: π^0, η, K_S decays

Direct $\Upsilon(1S)$: $(50.9 \pm 8.2 \pm 9.0)\%$

From $\chi_b(1P)$: $(27.1 \pm 6.9 \pm 4.4)\%$

From $\chi_b(2P)$: $(10.5 \pm 4.4 \pm 1.4)\%$

From $\Upsilon(2S)$: $(10.7^{+7.7}_{-4.8})\%$

From $\Upsilon(3S)$: $(0.8^{+0.6}_{-0.4})\%$

Input in theoretical calculations of Bottomonium cross sections

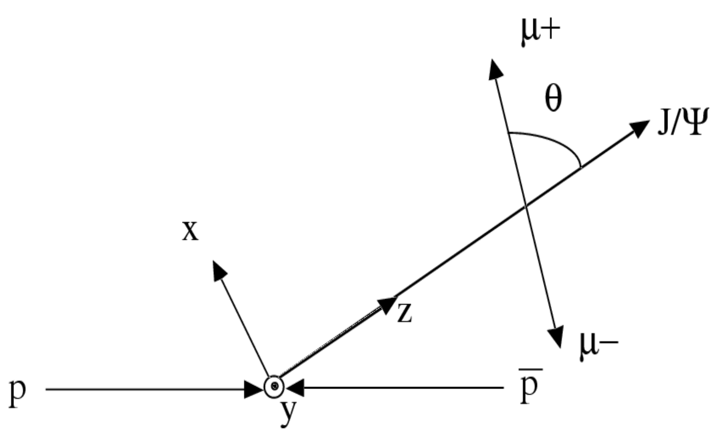
J/ψ Polarization

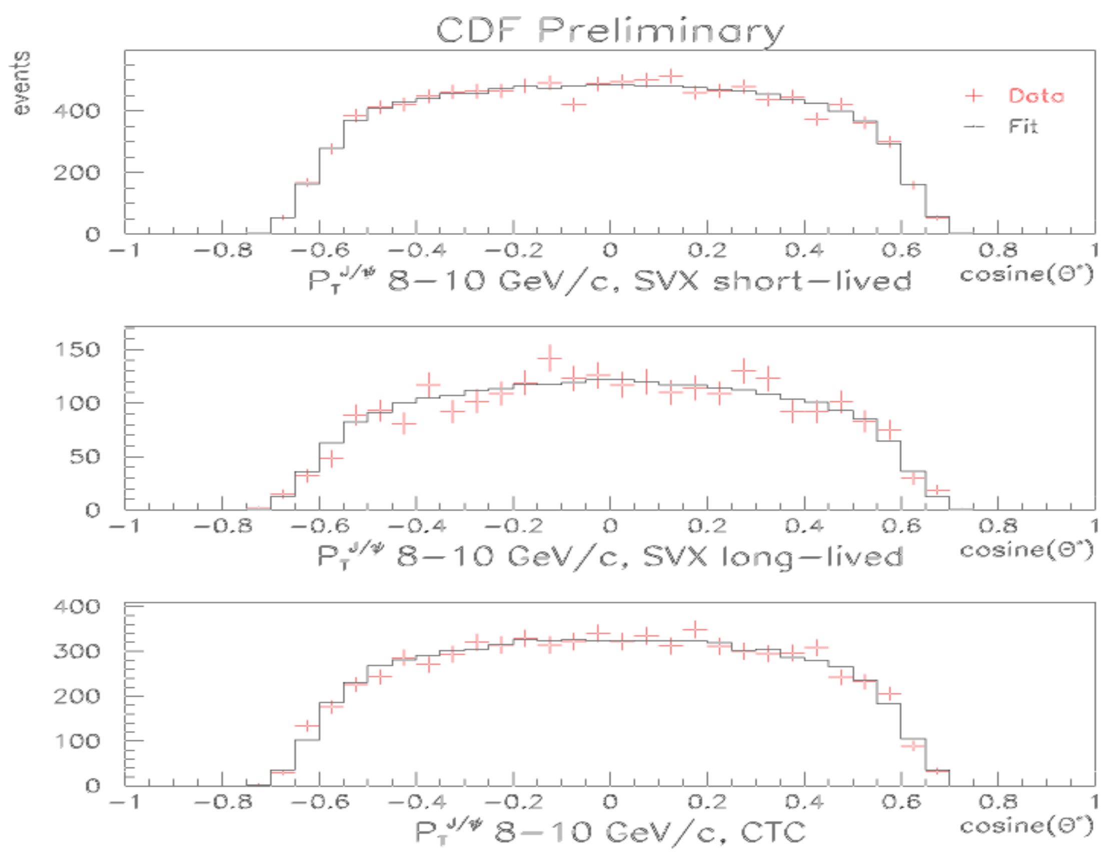
- All CDF Run I data, **∫L dt = 110 pb^{-1}**
- $p_T > 4$ GeV, $|y| < 0.6$
- Small acceptance at large $|\cos\theta|$
- χ^2 fit using templates for longitudinal and transverse polarization

$$d\Gamma / d\cos\theta \propto 1 + \alpha\cos^2\theta$$

$$\alpha = 1 \quad transverse$$

$$\alpha = -1 \quad longitudinal$$



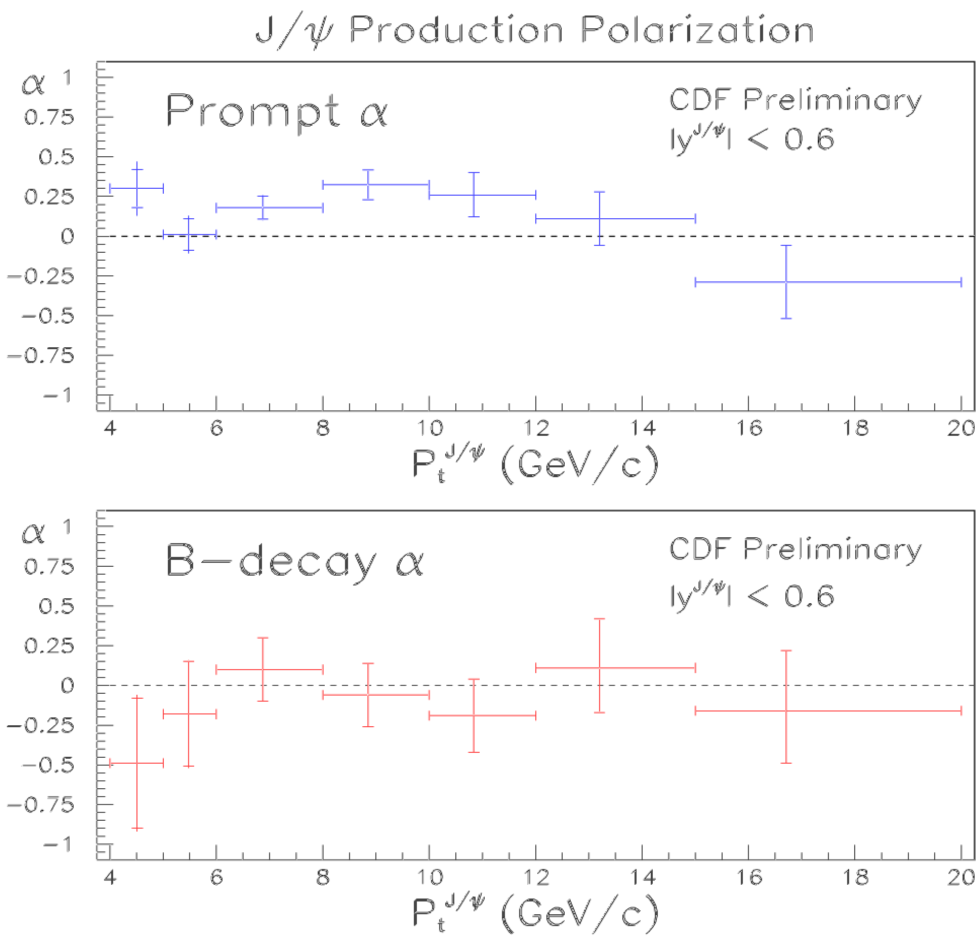


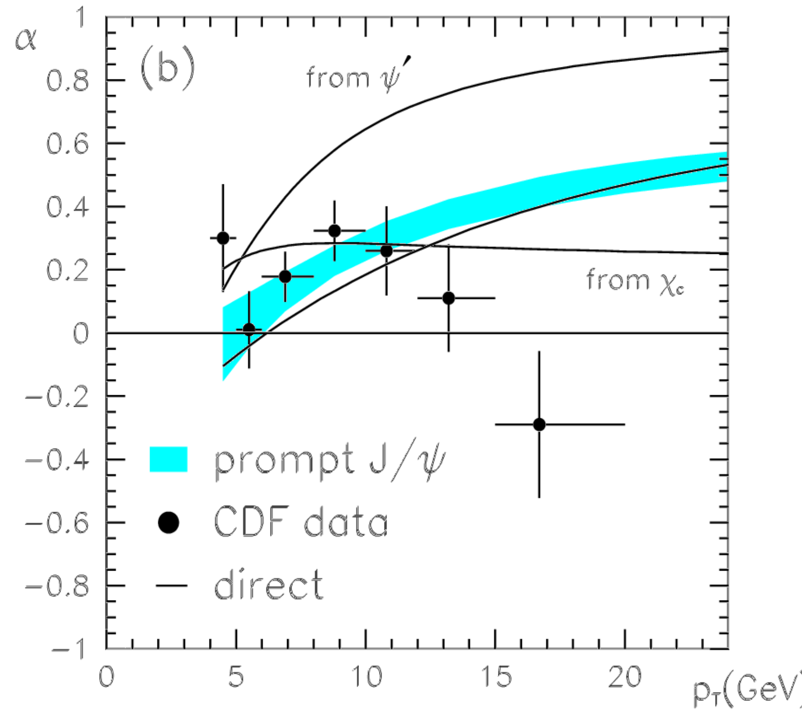
CDF, PRL 85 (2000) 2886

J/ψ Polarization

CDF, PRL 85 (2000) 2886

Braaten, Kniehl, Lee
PRD 62 (2000) 094005



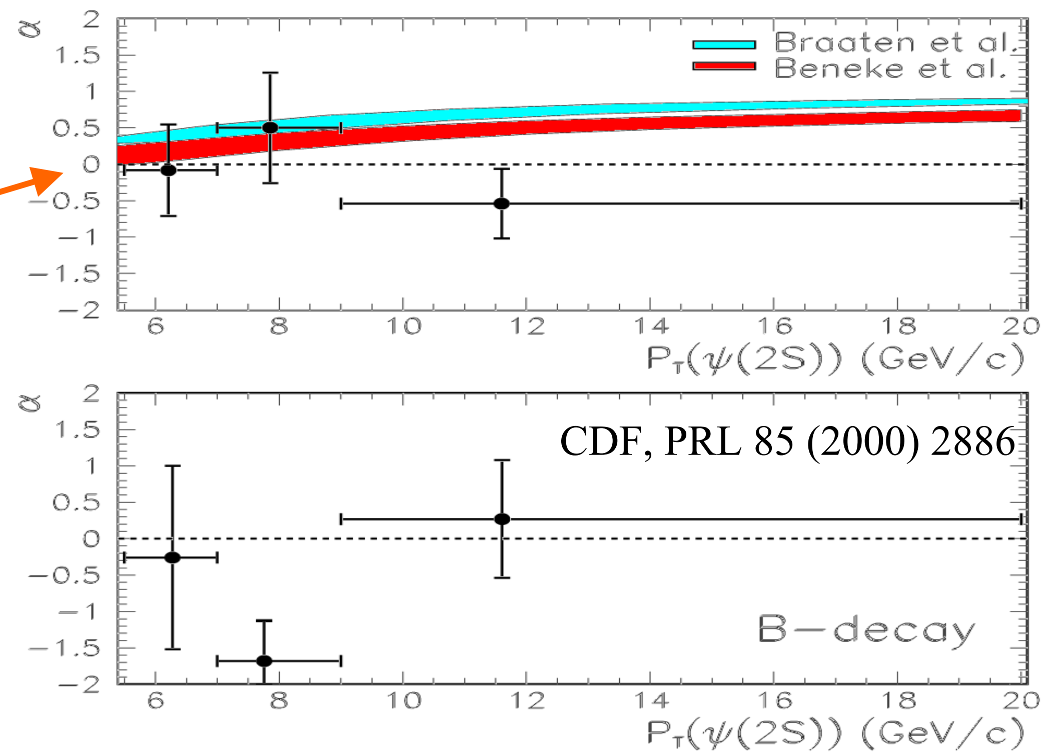


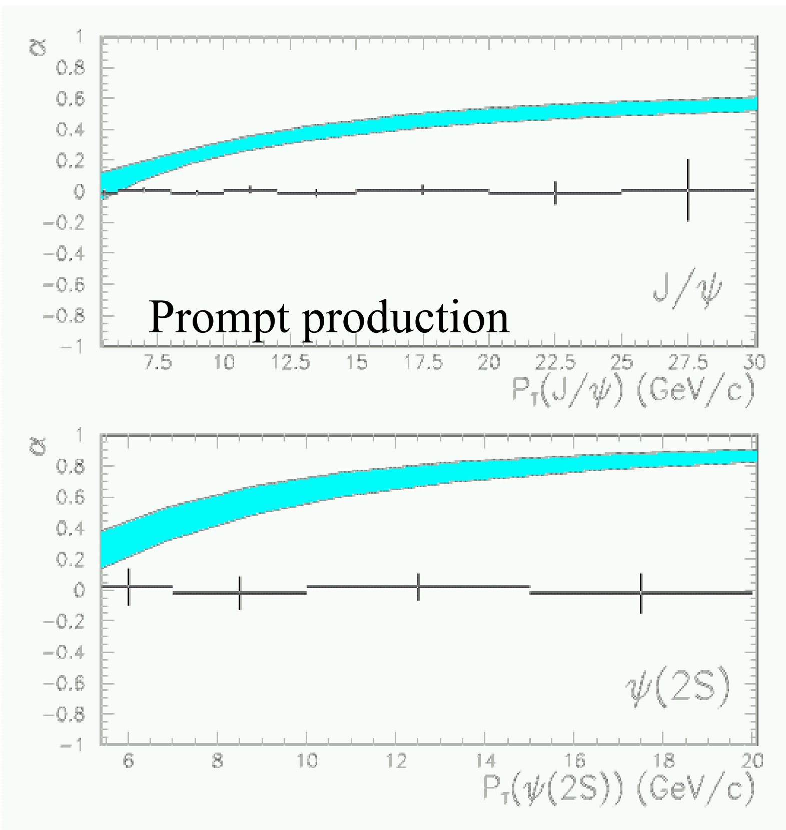
- Need to take into account $\psi(2S)$ and χ_c contributions
- Data do not show a trend towards transverse polarization at large p_T
- Phenomenological models give better description (E.g. **colour evaporation model:** mostly unpolarized J/ψ at large p_T)

J/ψ from B decays essentially unpolarized

ψ(2S) Polarization

- Same procedure, limited statistics
- Preferable to J/ψ since no **contamination** from indirect production
- Inconclusive



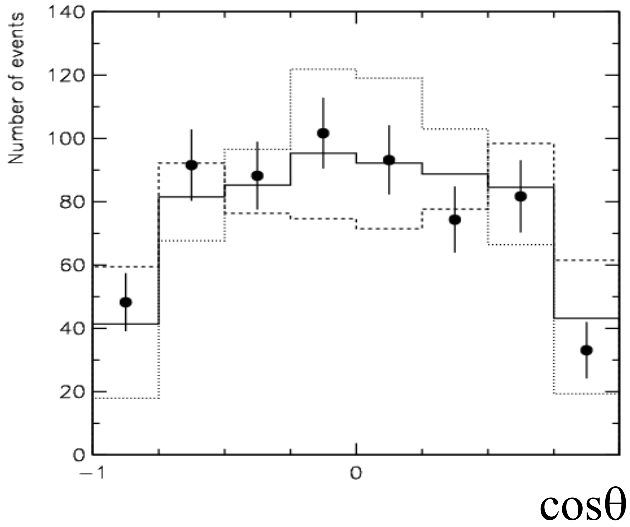


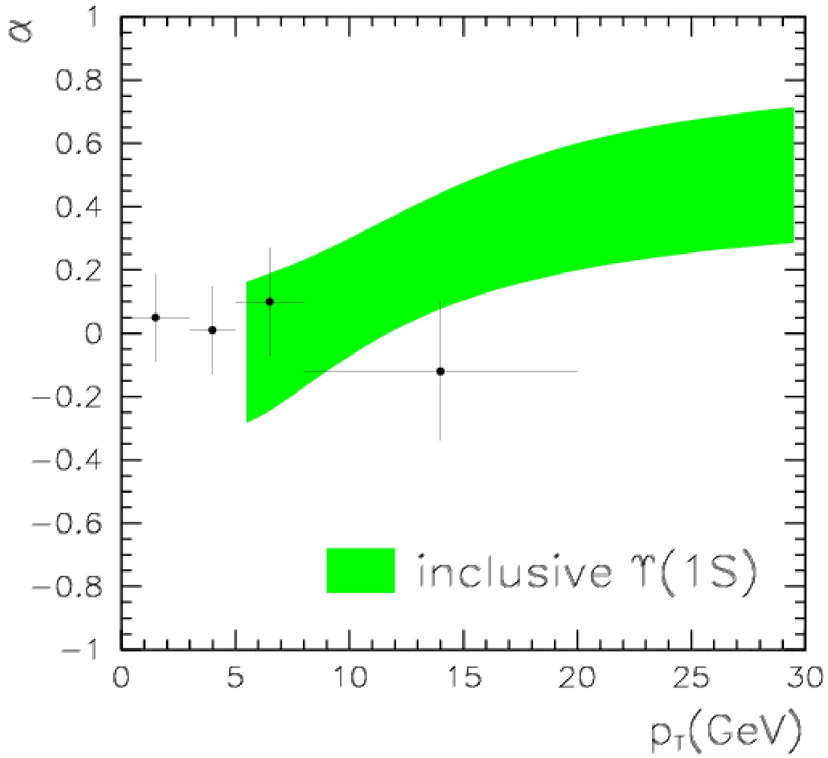
CDF study :

- Assume factor 50 in effective statistics
  - 2 fb^{-1}, better Silicon coverage
- Lower dimuon trigger threshold (1.5GeV)
  - Able to measure down to $p_T(J/\psi)$ of ≈ 0

Υ Polarization at CDF

Run I:
PRL 88 (2002)161802





$|y| < 0.4$
$8 < p_T < 20$ GeV/c

$1 + \alpha \cos^2\theta$
$\alpha = -0.12 \pm 0.22$

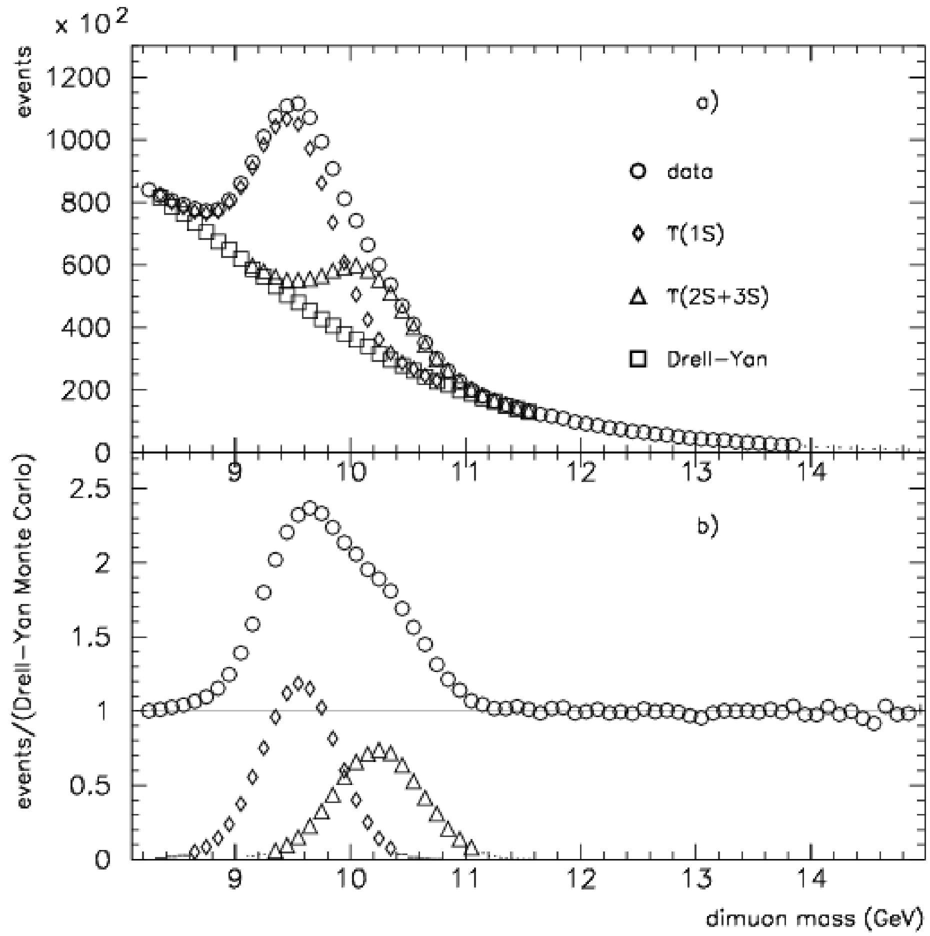
- similar to $c\bar{c}$ → as yet inconclusive
- Insufficient data with $p_T > 20$ GeV/c

E866/Nusea, $\sqrt{s}$=38.8 GeV

$p + Cu \rightarrow \mu^+\mu^- X$
(800 GeV proton beam)

$0 < x_F < 0.6$

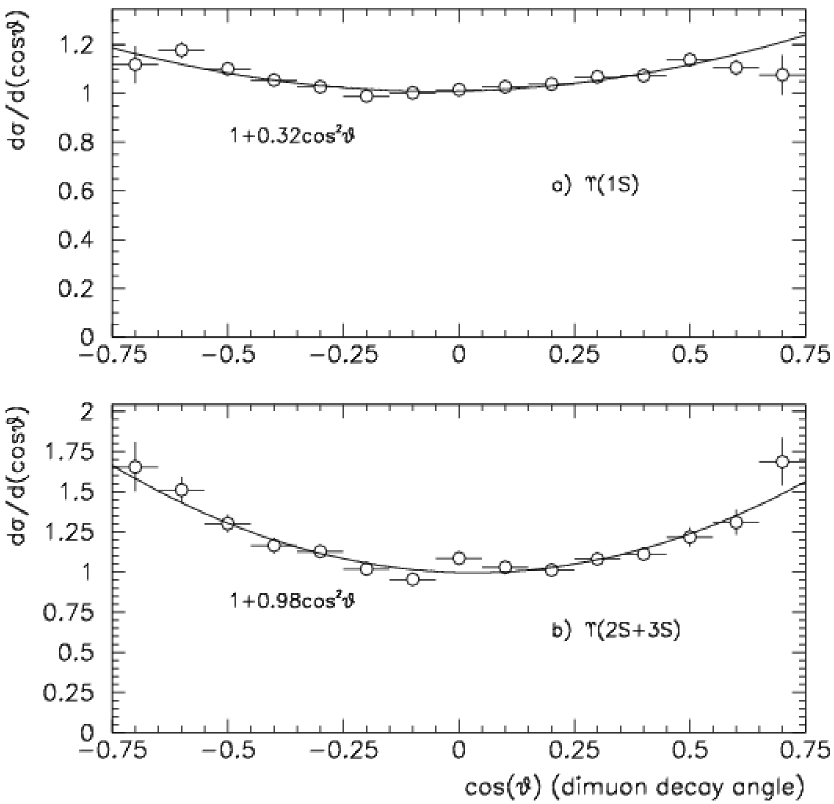
$p_T < 4$ GeV/c
(transverse to beam axis)

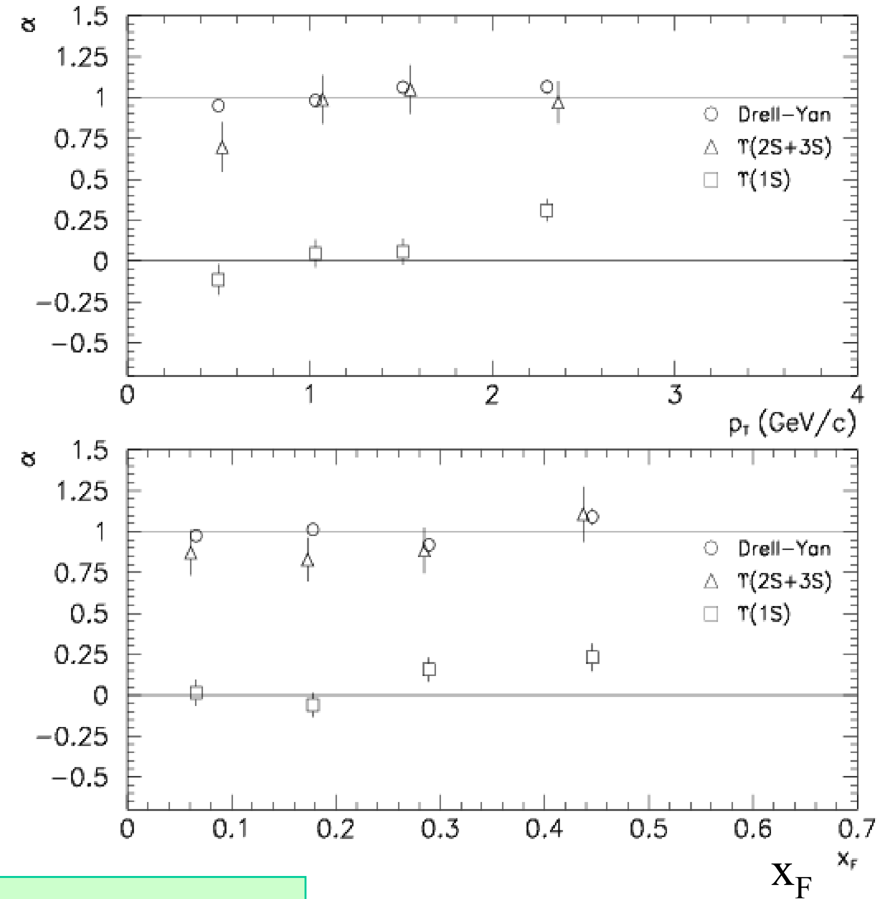


- Υ(2S) and Υ(3S) not distinguished
- Subtract Drell-Yan μμ continuum (100% transverse polarization)
- sideband fit: α=1.008 ± 0.016 ± 0.020

E866/Nusea, Υ polarization

cosθ distributions for $p_T > 1.8$ GeV/c





- inclusive Υ(1S):

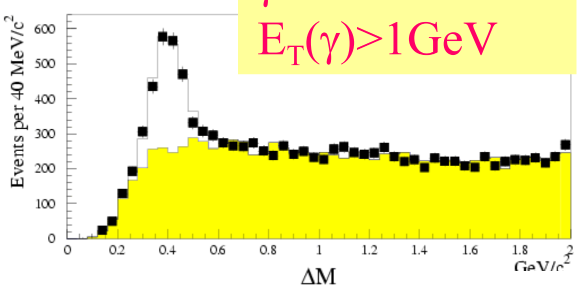
NRQCD: α= 0.28 to 0.31, avg over p_T, x_F
Observed: α= 0.07± 0.04(stat)± 0.06(sys)

- inclusive Υ(2S) + Υ(3S):

No explicit NRQCD prediction
Large observed transverse polarization, in contrast with charmonium

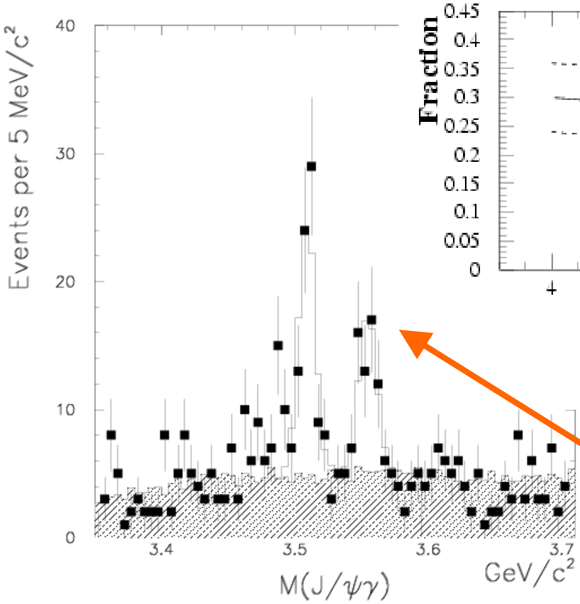
Run II – (CDF/D0 on χ_c)

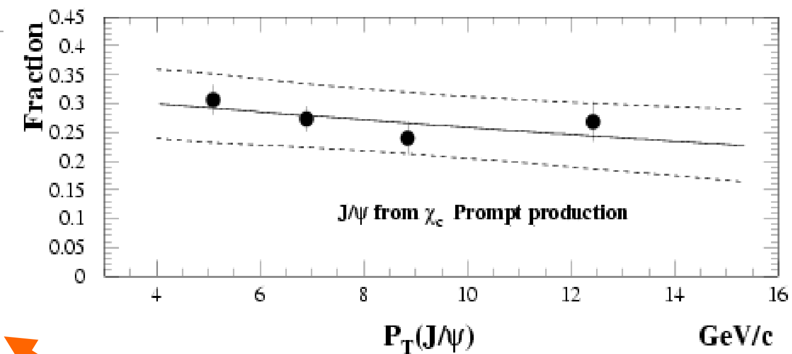
γ in calorimeter
$E_T(\gamma)$>1GeV



CDF - Run I

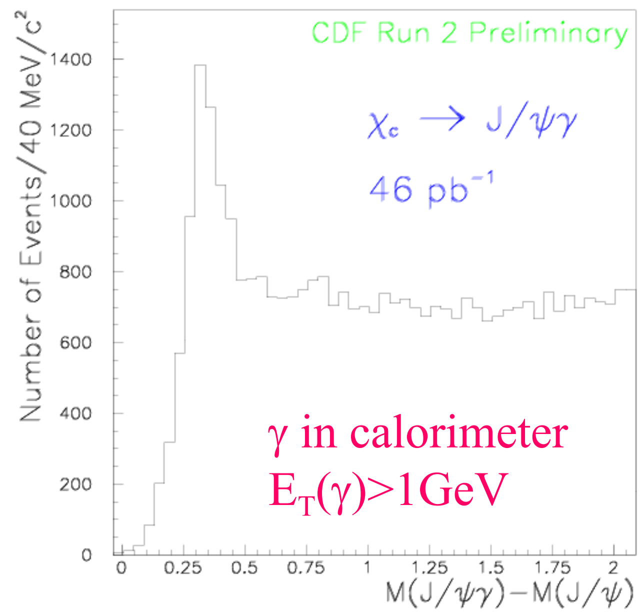
PRL 79 (1997) 578
PRL 86 (2001) 4472



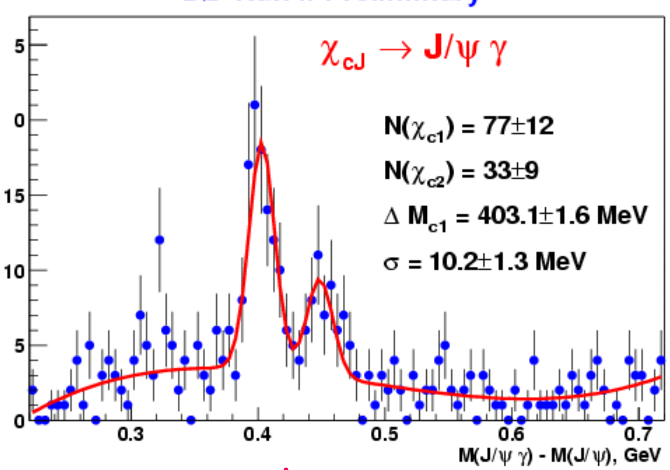


γ conversions

CDF Run II



γ in calorimeter
$E_T(\gamma)$>1GeV



γ conversions

$\sigma\chi_{c2}/\sigma\chi_{c1} = 0.96 \pm 0.27(stat) \pm 0.11(sys)$ (CDF)

F. Maltoni (NRQCD prediction), 1.1 ± 0.2

Tevatron/Fixed Target Summary

- *Tevatron:*
  - Direct J/ψ and ψ(2S) production (CDF) is in excess of CSM predictions by a factor of ~50
  - J/ψ cross section in the $(2.5 < |\eta^{J/\psi}| < 3.7)$ range (D0) consistent with CDF data for central J/ψ production
  - New cross sections, at low p_T, available. Need more theory calculations
  - J/ψ and ψ(2S) polarization measurements (CDF) appear not to support the COM prediction (more statistics needed)
  - $\sigma\chi_{c2}/\sigma\chi_{c1} = 0.96 \pm 0.27(stat) \pm 0.11(sys)$ (CDF); NRQCD prediction: 1.1 ± 0.2
  - Same shape for $d\sigma/dp_T$ vs p_T for 3 Υ(n) states. Fits of CS and CO matrix elements describe the Υ(n) cross sections (CDF)
  - Υ(1S) polarization: $\Gamma_L/\Gamma = 0.39 \pm 0.11$ $(\alpha = -0.12 \pm 0.22)$ (CDF) consistent with COM calculations
  - Results on production of Υ(1S) from χ_b decays

    Υ(1S) direct production: $[50.9 \pm 8.2(stat) \pm 9.0(sys)]$ % (CDF)
  - Diffractive to total production rate for $|\eta|<1$ is $[1.45 \pm 0.25]$% (CDF)

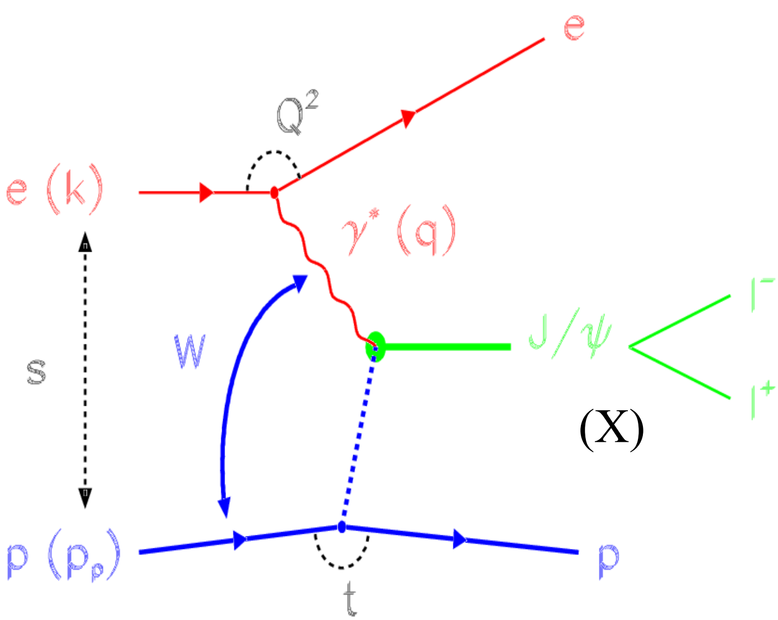
Tevatron/Fixed Target Summary

- Fixed Target energies:
  - ♦ Y(1S): significant positive transverse production polarization for either p_T > 1.8 GeV/c or x_F > 0.35 (E866)
  - ♦ Y(2S+3S) (unresolved): large transverse production polarization at all measured p_T and x_F (E866)

Quarkonia at HERA

HERA ("Run I" ended in September 2000, $\int L\,dt > 100\ pb^{-1}$):

- ***$e^{\pm}$ (27.5 GeV) → ← p (820/920 GeV) at $\sqrt{s}$ = 300/320 GeV***



$$Q^2 := -q^2$$

$$W^2 := (p_p + q)^2 \approx Q^2 / x$$

$$Q^2 :\approx xys$$

- DIS
  - $1 < Q^2 < 100\ GeV^2$
- Tagged/untagged photoproduction
  - Scattered e not seen in main detector
  - Median $Q^2 \cong 10^{-4}\ GeV^2$
- Decays into e^+e^- and $\mu^+\mu^-$
- Central tracking ($|\eta| < 1.8$)
  - 30 < W < 180 GeV

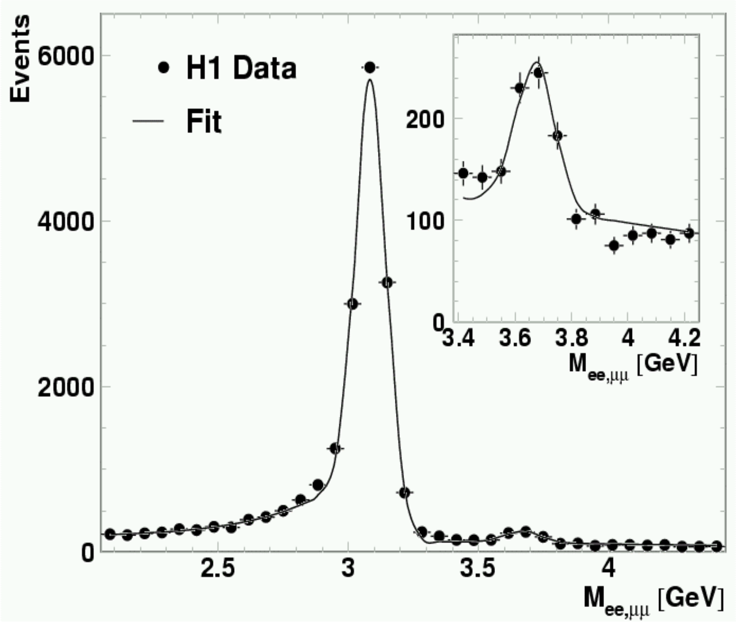
HERA "Run II" under way;

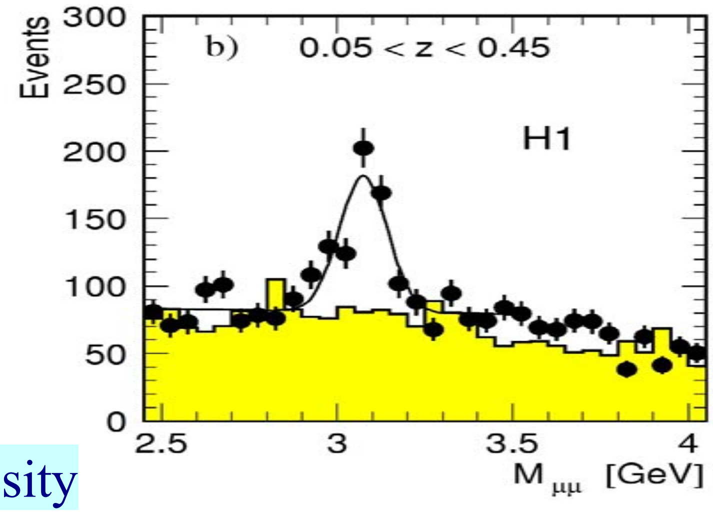
Delivered ~ $\int L\,dt = 22\ pb^{-1}$ so far. Achieved up to $0.8\ pb^{-1}$/day. $\int L\,dt \sim 100\ pb^{-1}$ expected by the Sept. 2004); $e^{\pm}$ polarized beams.

J/ψ at HERA

$$z = \frac{P_p . P_\psi}{P_p . P_\gamma} = \frac{E_\psi}{E_\gamma} \quad \text{in p rest frame}$$

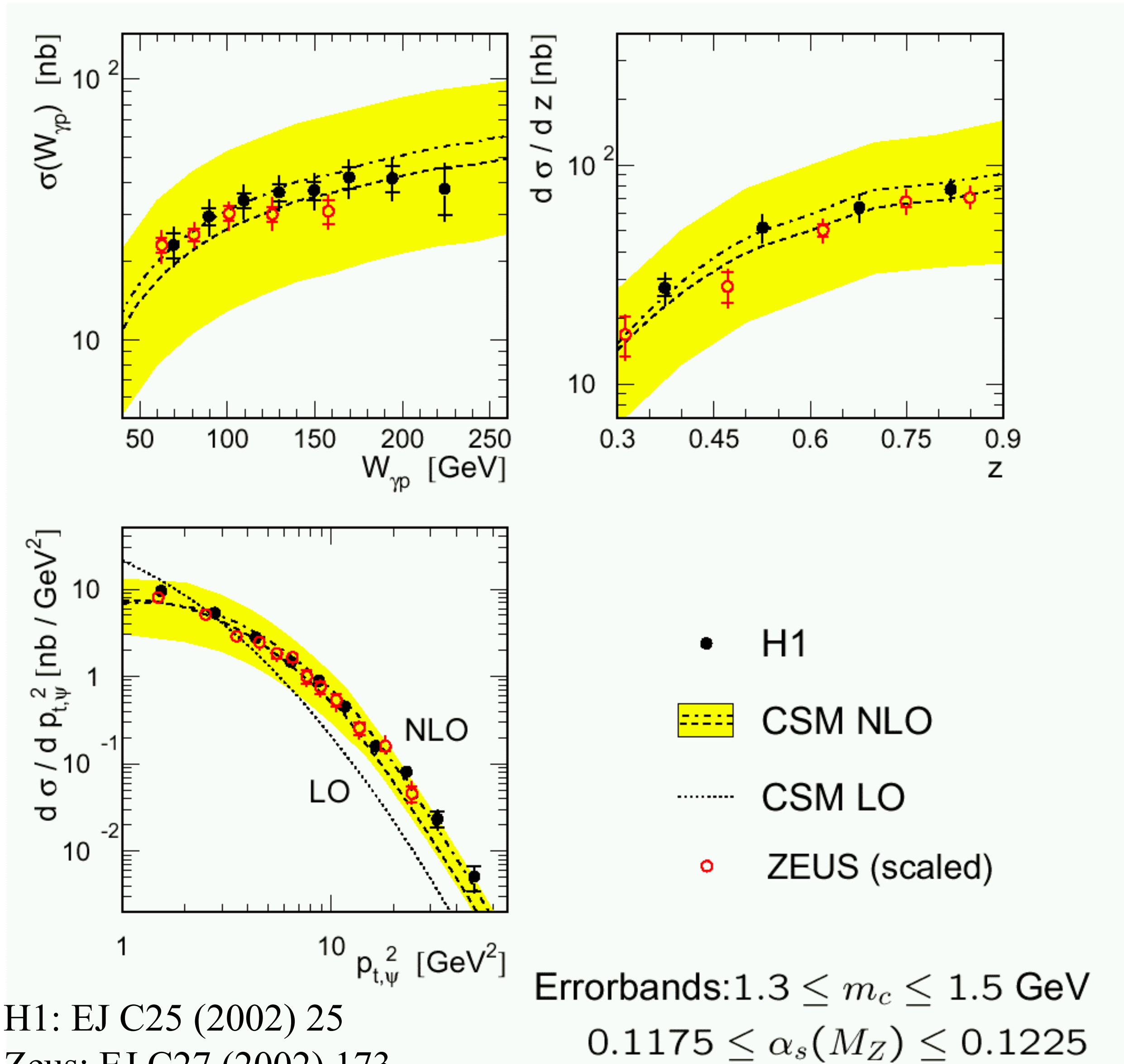
- Order of magnitude comparable
  - "Elastic" $z \approx 1\ (M_X = m_p)$
  - p diffractive dissociation $z \approx 1\ (\sigma \propto 1/M_X^2)$
  - "Inelastic" $z < 1$
- At small z contributions from
  - Resolved photon
  - B production
- Background increases with decreasing z





High Q^2/p_T will greatly benefit from increase in luminosity

J/ψ Photoproduction: CSM

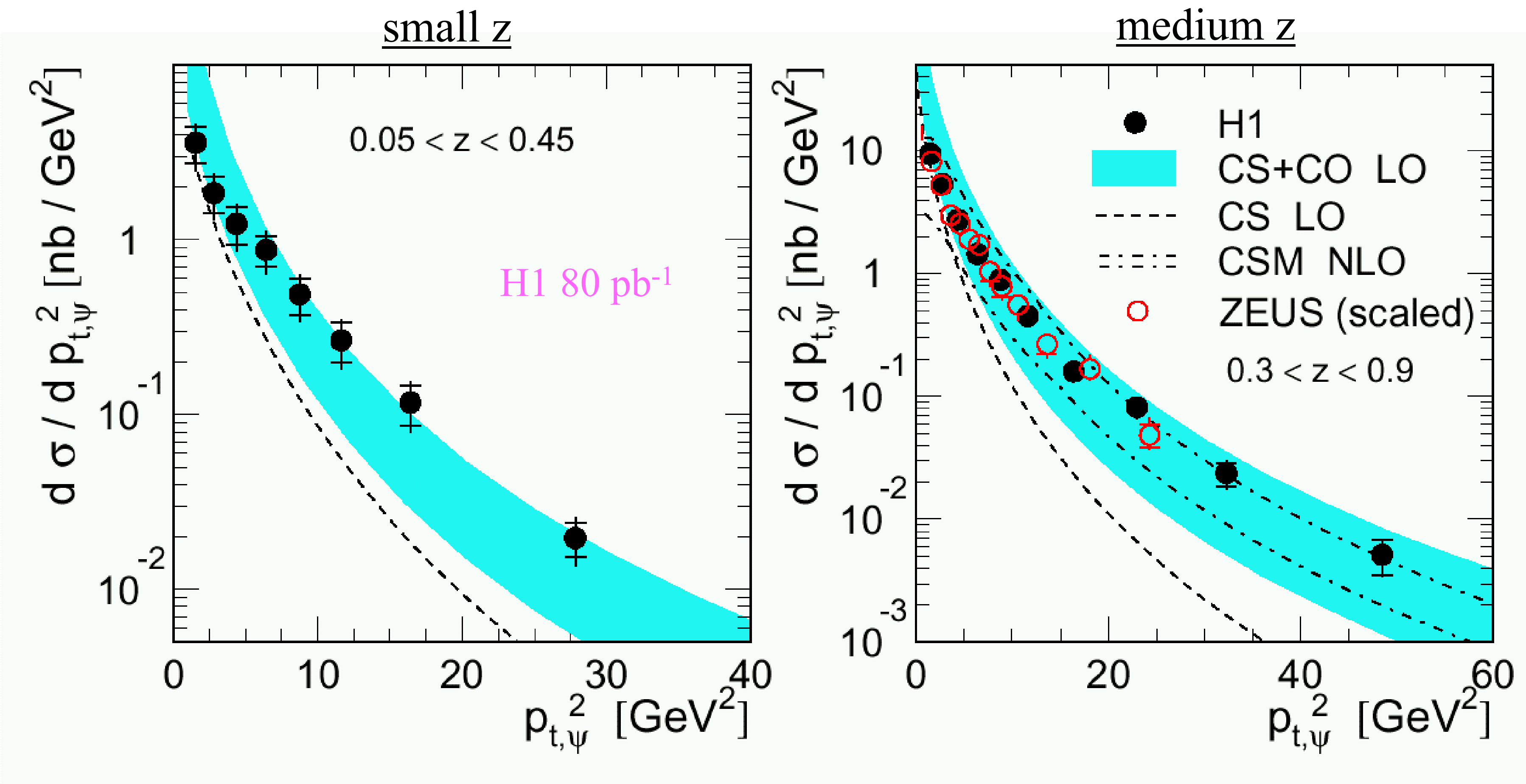


H1: EJ C25 (2002) 25
Zeus: EJ C27 (2002) 173

Colour Singlet Model: NLO calculation of direct photon gluon fusion process (M.Krämer)

LO: too steep
NLO: good agreement

J/ψ Photoproduction: NRQCD



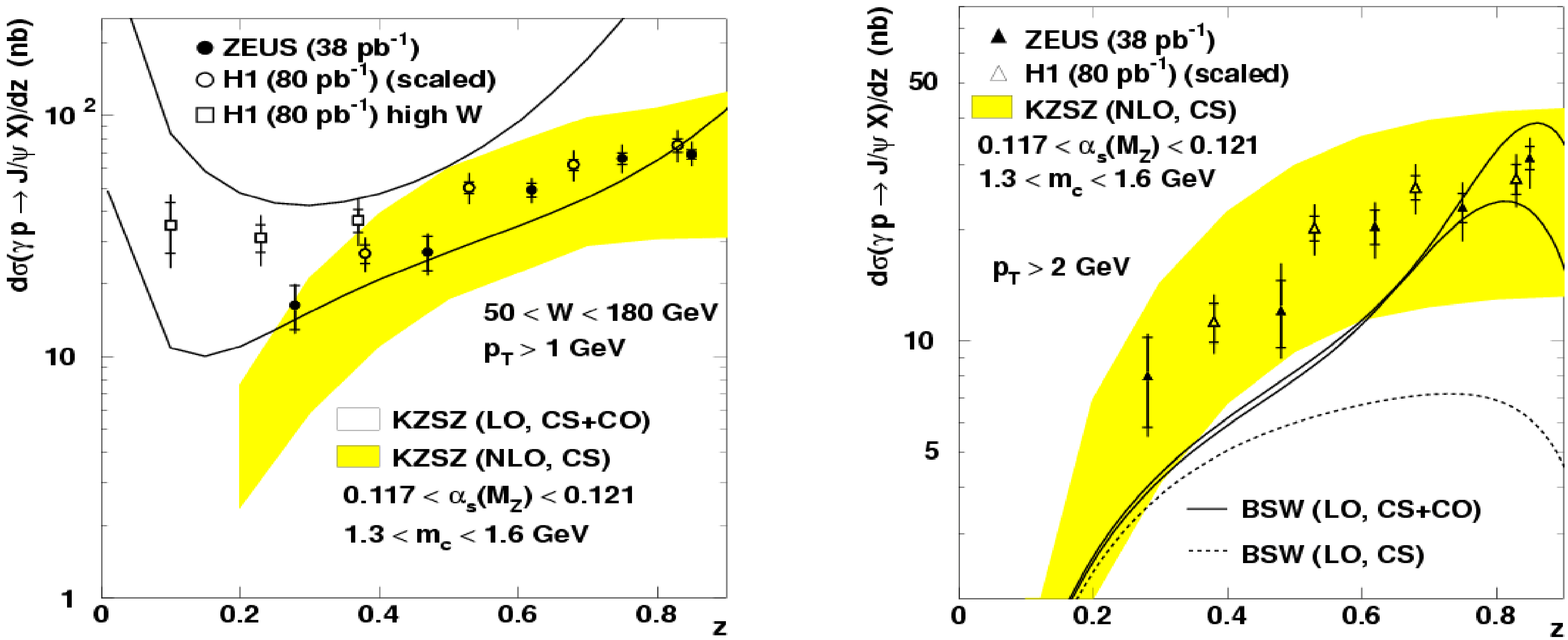
H1: EJ C25 (2002) 25
Zeus: EJ C27 (2002) 173

- p_T spectra similar at low and medium z
- NRQCD (including CS and CO): softer than data
    - Contributions from B decays in data?

J/ψ Photoproduction: inelasticity

EJ C25 (2002) 25
EJ C27 (2003) 173

CO long-distance ME taken from fit to CDF data



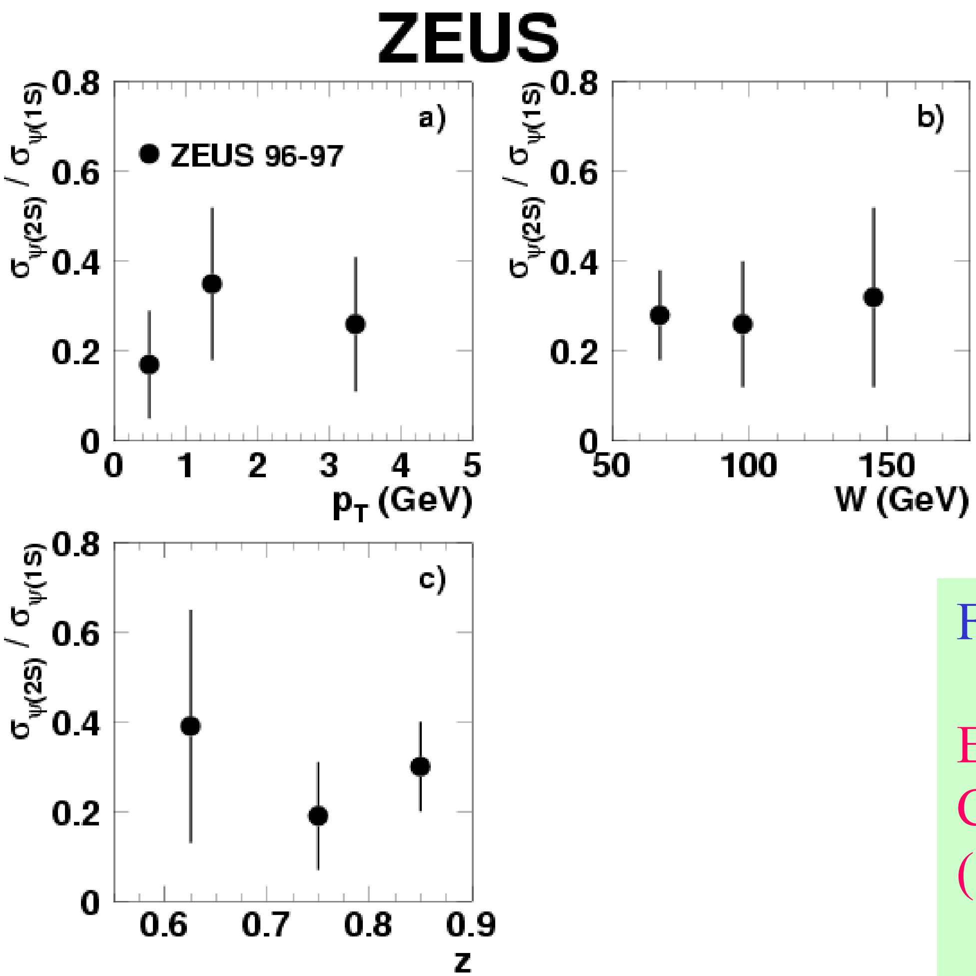
NLO CSM agrees with data; Theoretical uncertainties do not allow strong conclusions on CO

Left: NRQCD describes shapes (large LDME uncertainties)

Right: Damping at high z for BSW (LO, CS+CO) ⇒ better agreement

Photoproduction: $\sigma_{\psi(2S)} / \sigma_{\psi(1S)}$

EJ C27 (2003) 173



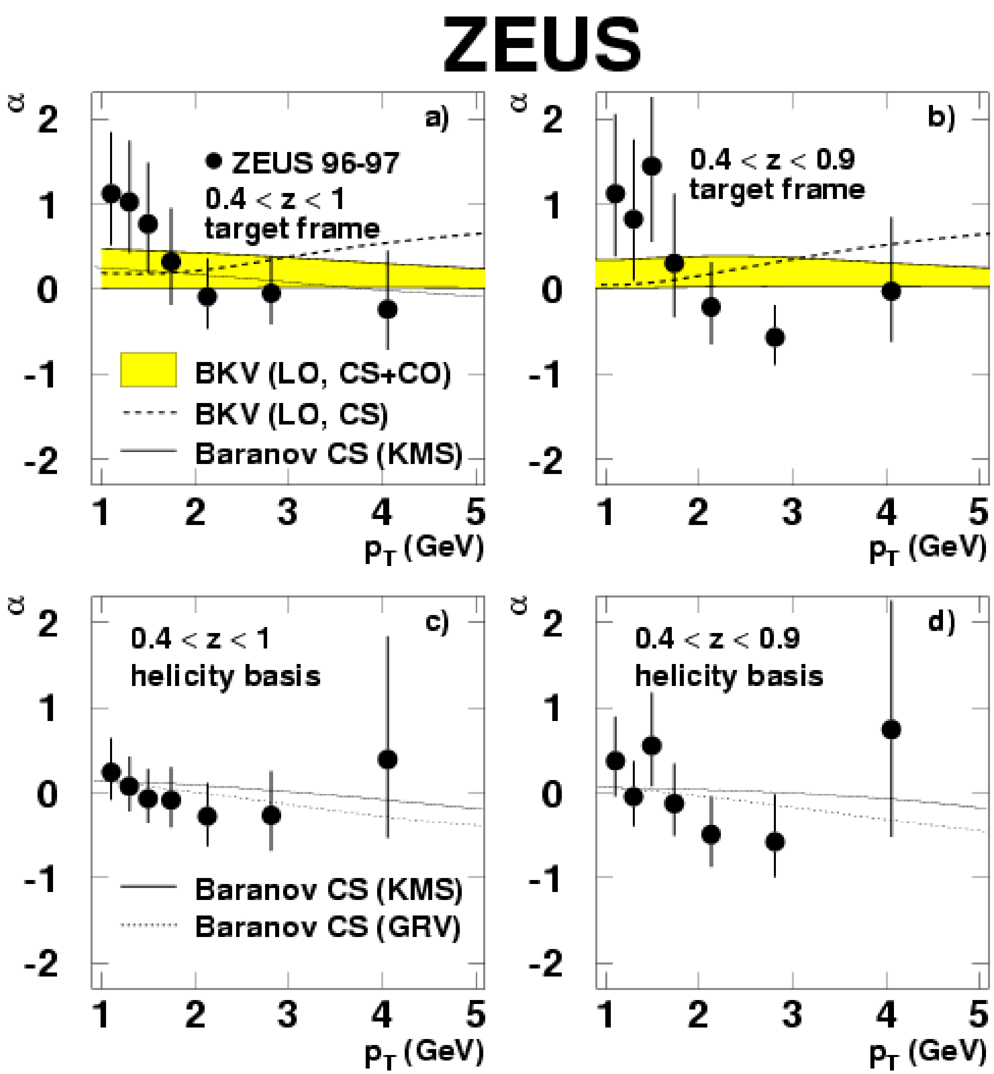
$$\sigma_{\psi(2S)} / \sigma_{\psi(1S)} = 0.33 \pm 0.10^{+0.01}_{-0.02}$$

Flat, consistent with 0.24 from KZSZ (LO,CS)

Estimate of J/ψ fraction coming from ψ(2S)
Cascade decays consistent with expectations (15%)

Photoproduction: helicity

EJ C27 (2003) 173



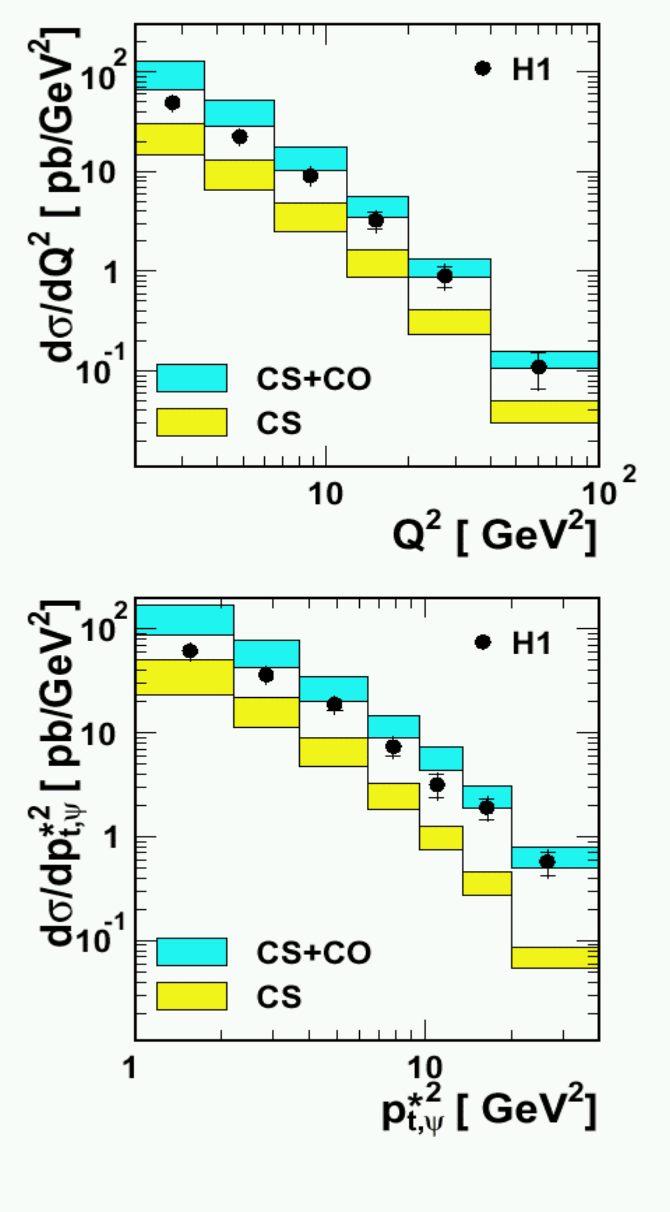
$dN/d\cos\theta^* \propto 1 + \alpha \cos^2\theta^*$

BKV – collinear calculations

Baranov – k_t-factorization

Statistics is not yet sufficient to discriminate between models

H1 - J/ψ Electroproduction



Data: $2 < Q^2 < 100$ GeV^2
$0.3 < z < 0.9$
$50 < W < 225$ GeV
$p_T^* > 1$ GeV
$\int L\,dt = 77$ pb^{-1}

EJ C25 (2002) 41

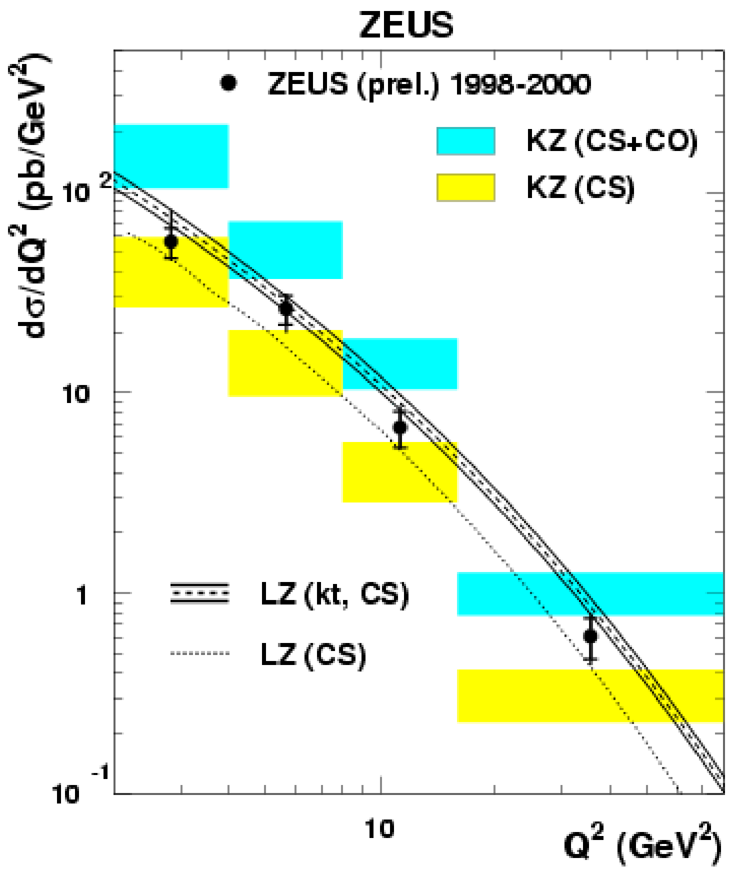
Theory: LO Colour Singlet Model
LO NRQCD (CS+CO)
(B.A.Kniehl, L.Zwirner, NP B621(2002) 337)

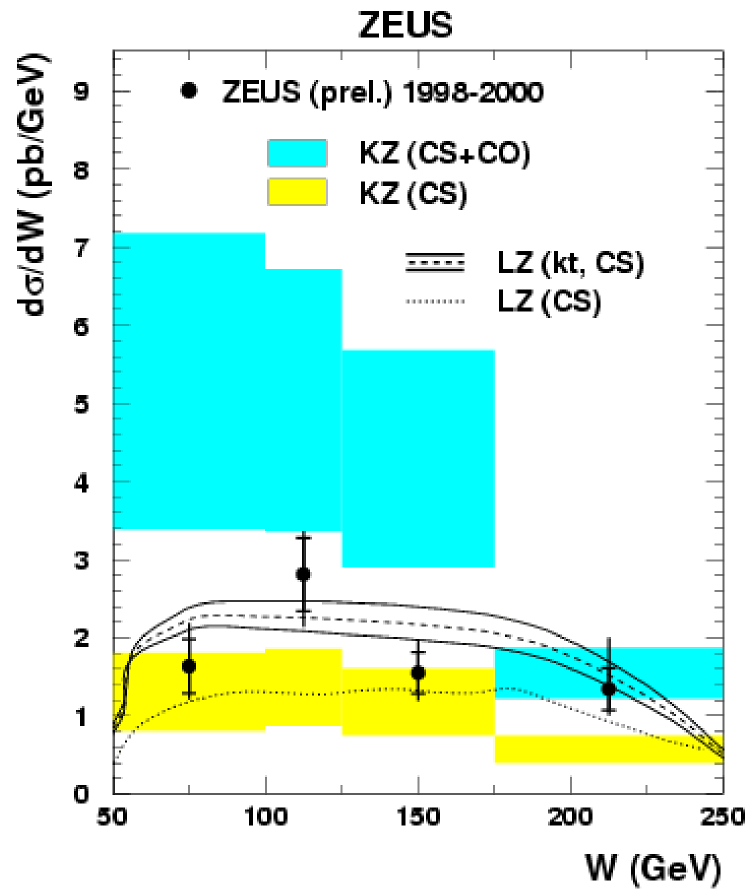
CS alone: normalization low, too steep in p_T

NRQCD (CS+CO): too high at low Q^2, p_T
better at high Q^2, p_T

Need: NLO calculations
More data at larger Q^2, p_T

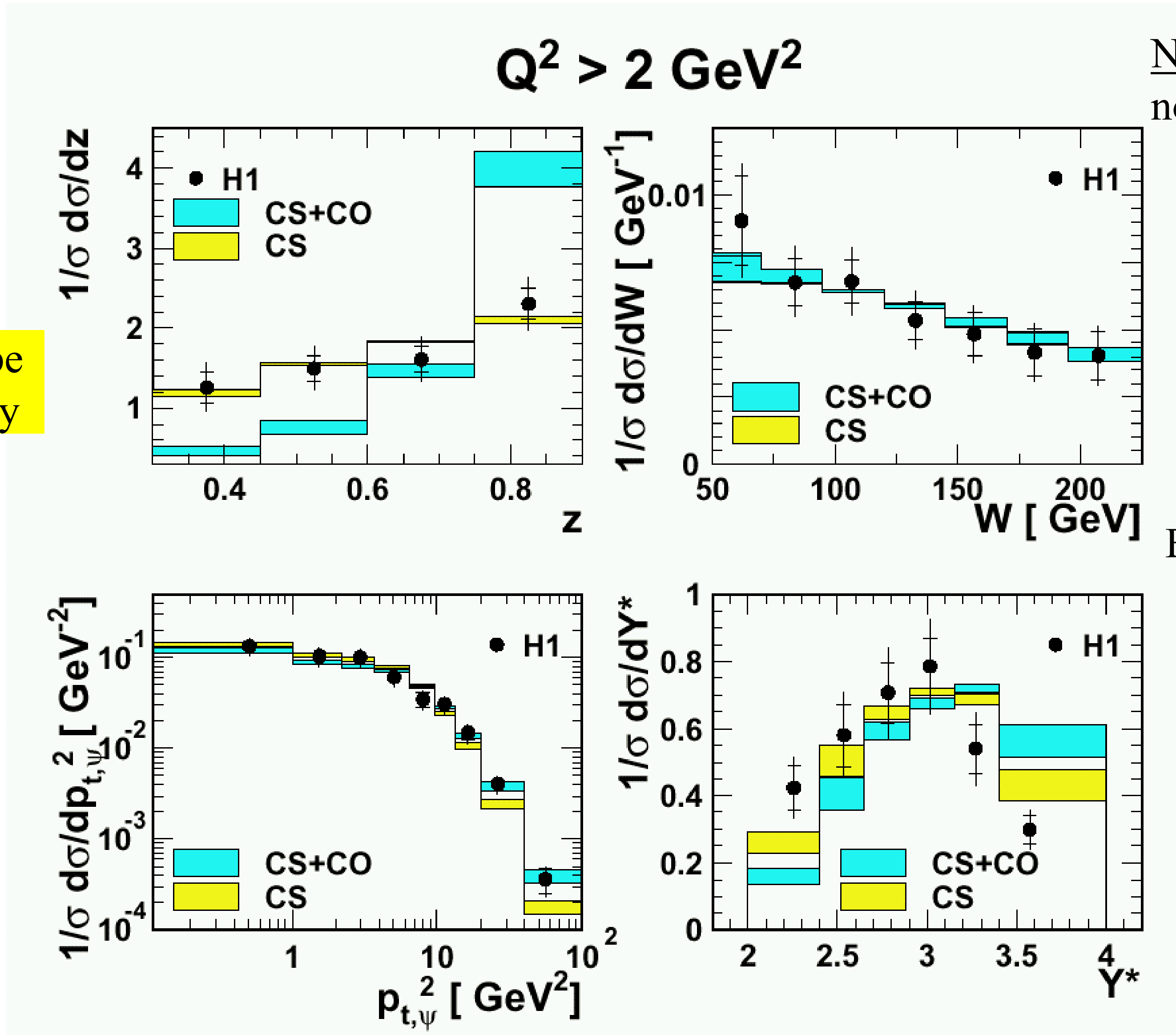
Zeus - J/ψ Electroproduction: Q^2 and W





- KZ(CS) and LZ(CS): lower but consistent with data
- KZ(CS+CO): mostly overshoots data
- LZ(kt, CS): agrees with data

H1 - J/ψ Electroproduction



Note: Theory normalized to data

Large shape discrepancy

EJ C25 (2002) 41

Rapidity in γp CMS

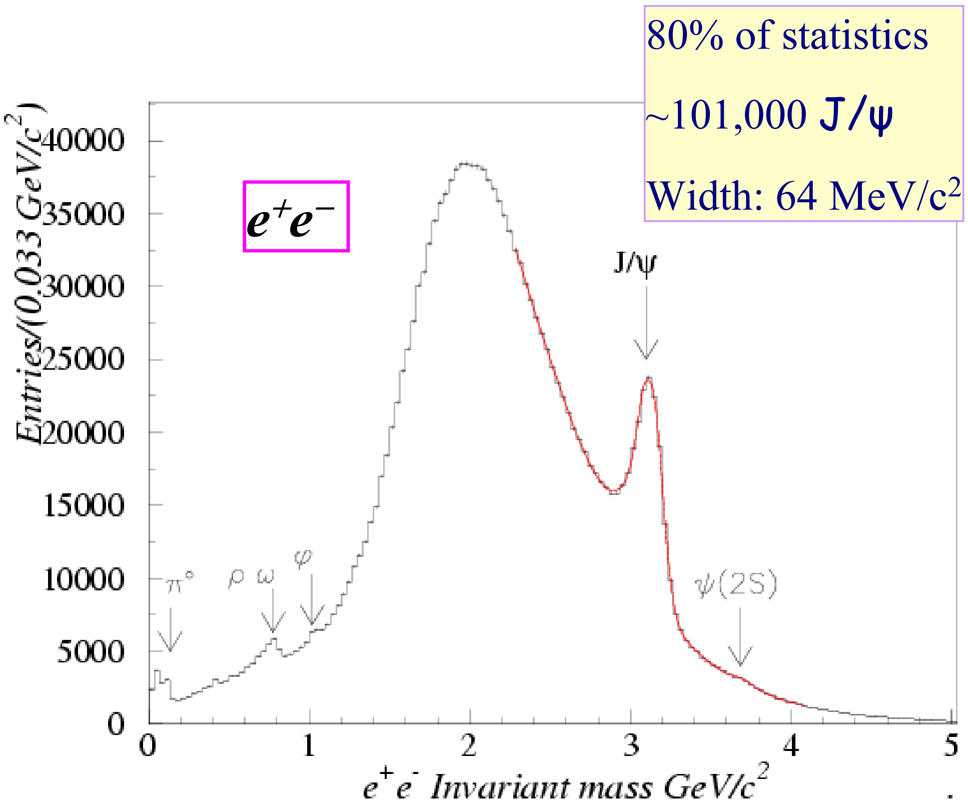
HERA photo/electro production summary

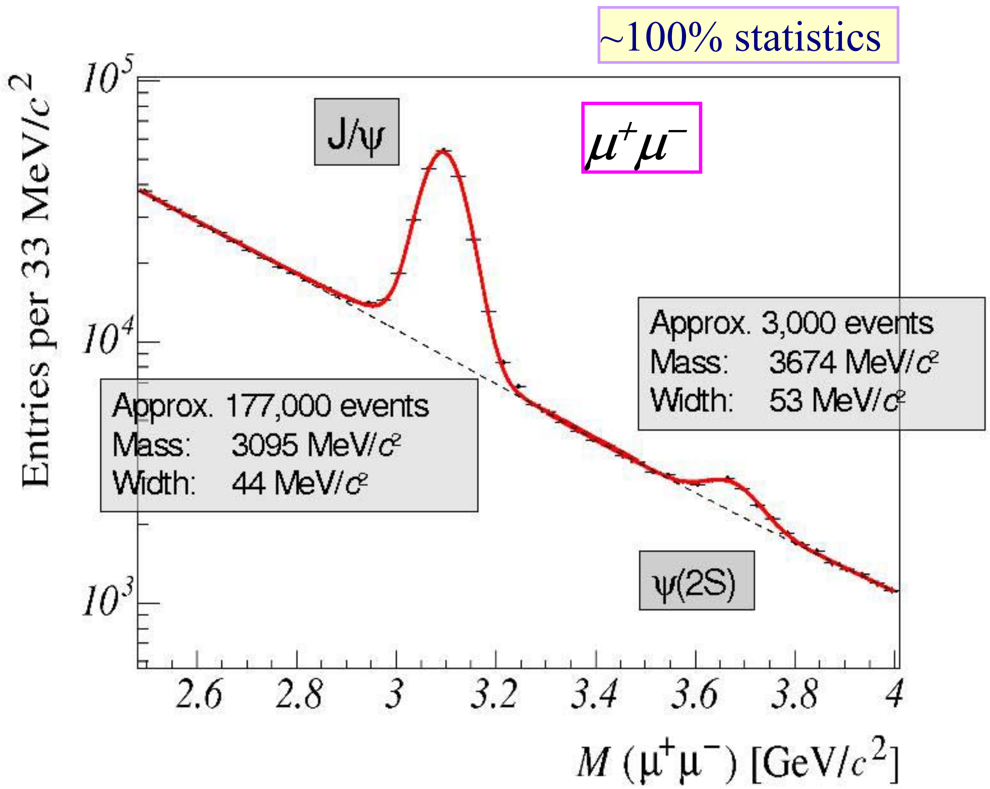
- Photoproduction
  - **NLO** corrections enable one to describe high production of J/ψ within **CSM**
  - Theoretical uncertainties are large: **CO** contributions cannot be excluded
- Electroproduction
  - **LO CS:** Below but consistent with data, except high p_T range (**NLO** corrections?)
  - **NRQCD (CS+CO):** too high at large z and small p_T^* values
  - **kt-factorization (CS):** agrees with data except at high p_T^* (too low) and in photon direction (too high)

HERA-B

Data taking of 30 October 2002 – 3 March 2003 provided:

- ~ 300,000 triggered J/ψ ($e^+e^-/\mu^+\mu^-$)
- ~ $210 \cdot 10^6$ Minimum bias events





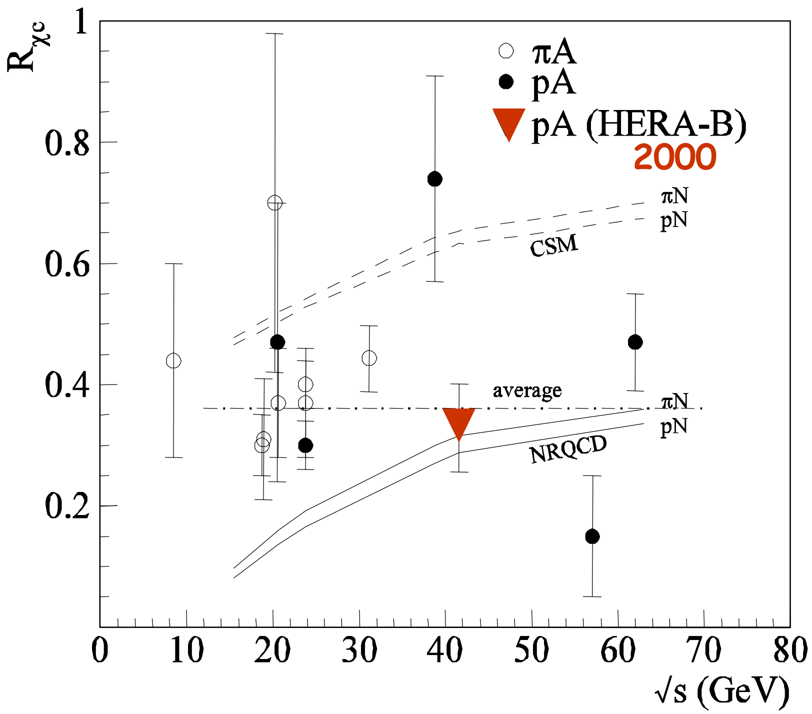
Charmonium Production : χ_c

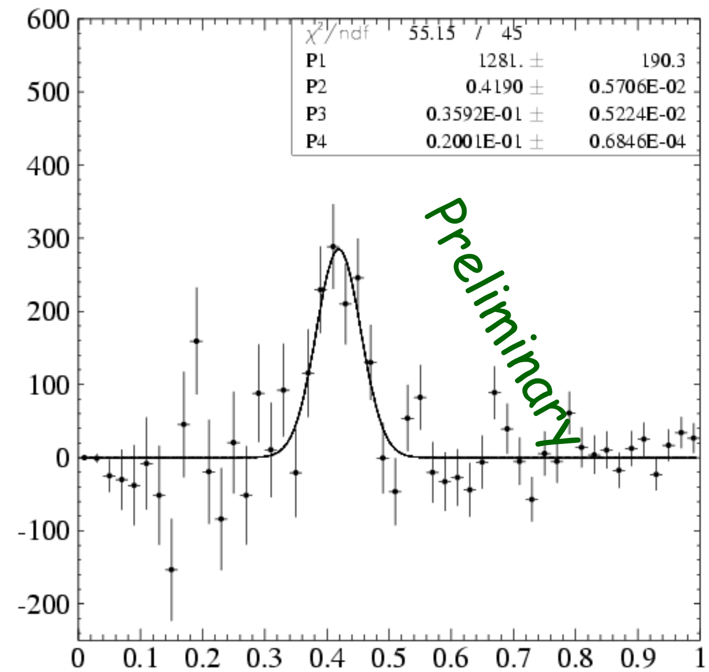
Fraction of J/ψ produced via χ_c

$\Delta M = M(J/\psi\ \gamma) - M(J/\psi)$

$$R_{\chi_c} = \frac{\sum \sigma(\chi_{ci}) Br(\chi_{ci} \rightarrow J/\psi\gamma)}{\sigma(J/\psi)_{tot}}$$

Only μ-channel, 2002/2003 data





~1300 χ_c in 15% of data

Measurement 2000 based on

380 ± 74 χ_c (both $\mu^+\mu^-$, e^+e^-)

$R_{\chi c} = 0.32 \pm 0.06_{stat} \pm 0.04_{sys}$

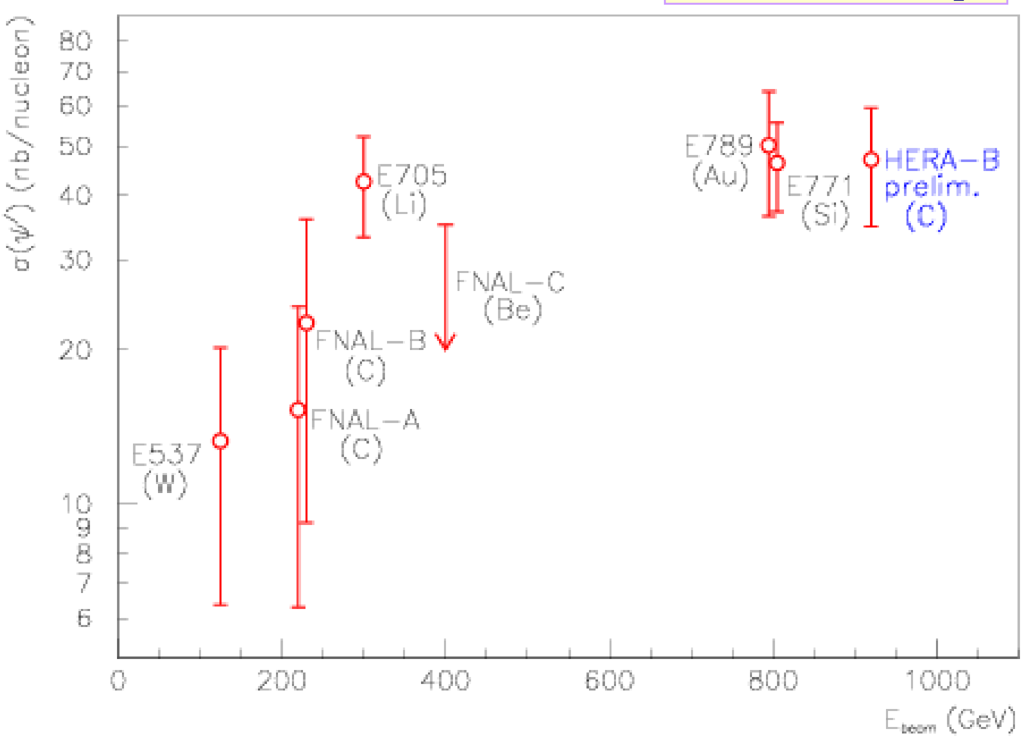
$R_{\chi c} = 0.21 \pm 0.05_{stat}$

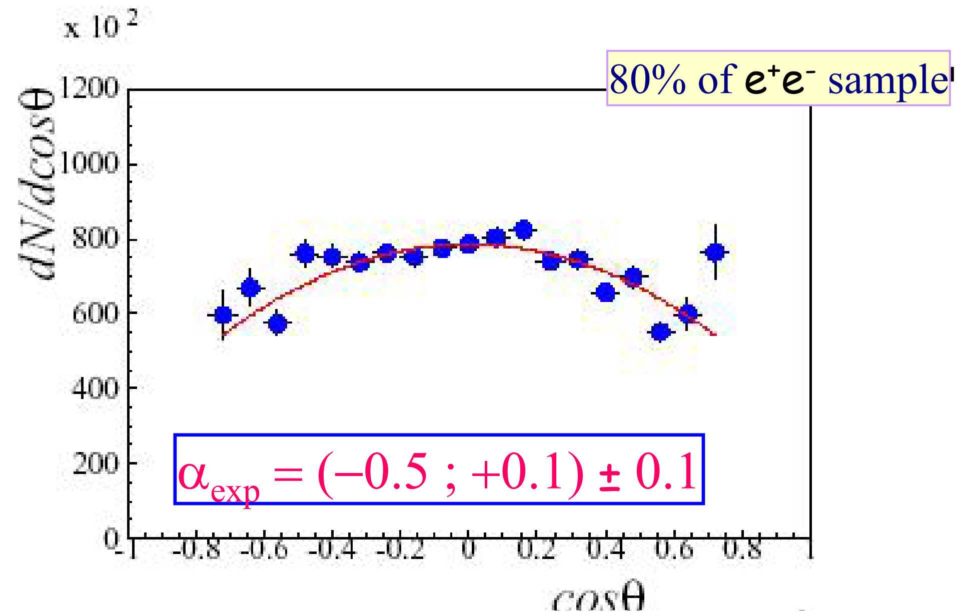
Electron channel gives compatible result.

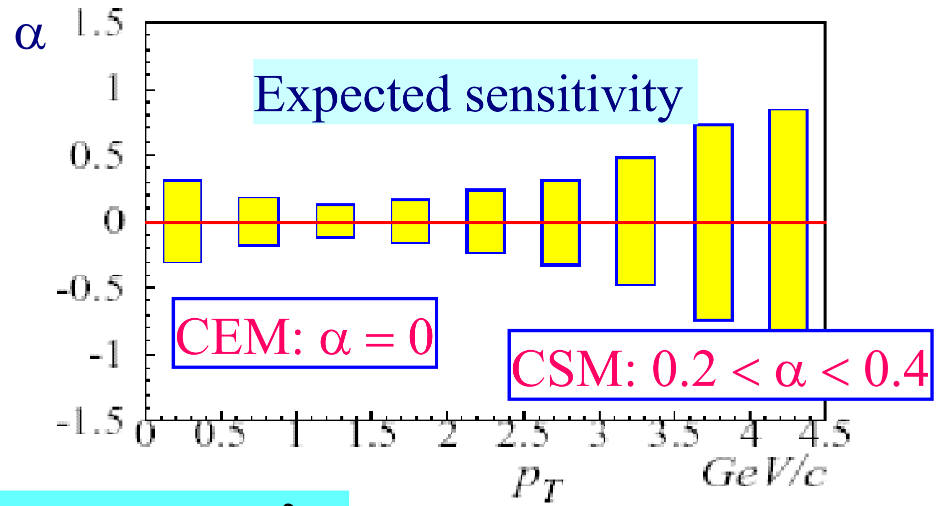
PL B561 (2003) 61

ψ(2S) to J/ψ ratio and J/ψ polarization

30% of e^+e^- sample







Use $\sigma(J/\psi) = 357 \pm 8_{stat} \pm 27_{sys}$ (E771, E789)

$\sigma(\psi(2S)) = 46 \pm 12$ nb/N

$R = \sigma(\psi(2S))/\sigma(J/\psi) = 0.13 \pm 0.02$

$$d\Gamma / d\cos\theta \propto 1 + \alpha \cos^2\theta$$
$$\alpha = 1 \quad transverse$$
$$\alpha = -1 \quad longitudinal$$

NRQCD: $0 < \alpha < 0.1$ for $1.5 < p_T < 4$ GeV/c, J. Lee(2000), resummation needed

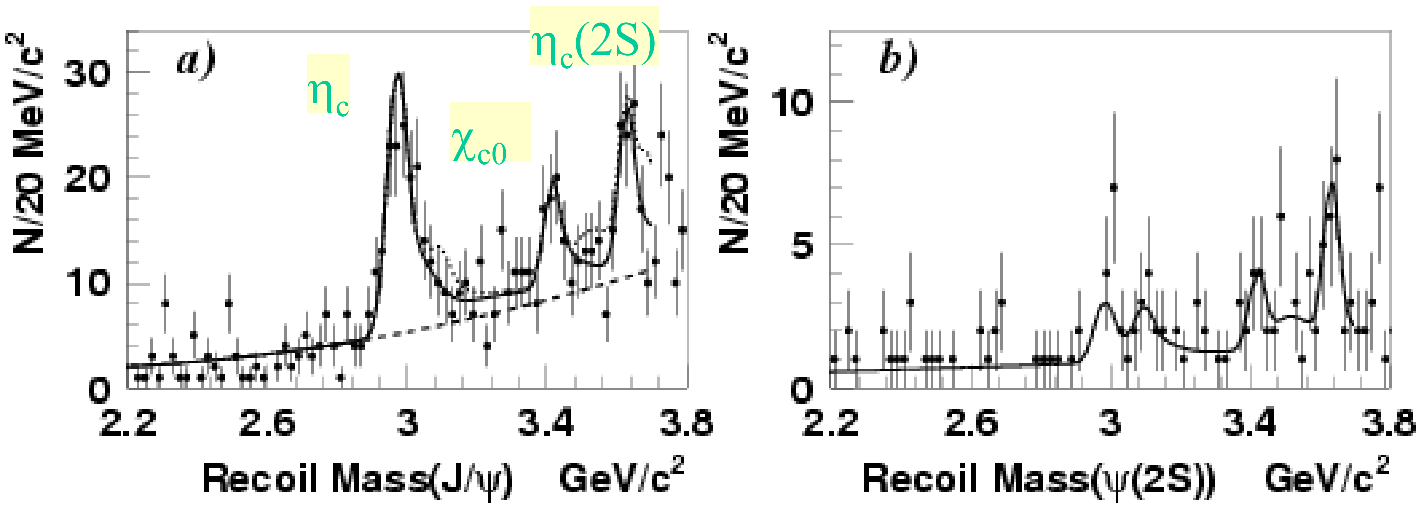
Vaia Papadimitriou (Fermilab)

Double $c\bar{c}$ production at BELLE

$e^+e^- \rightarrow J/\psi\ c\bar{c}$ $\quad$ $e^+e^- \rightarrow (c\bar{c})_{res}\ c\bar{c}$

PRL 89 (2002)142001
EPS-ID 562

$101.8\ fb^{-1}$

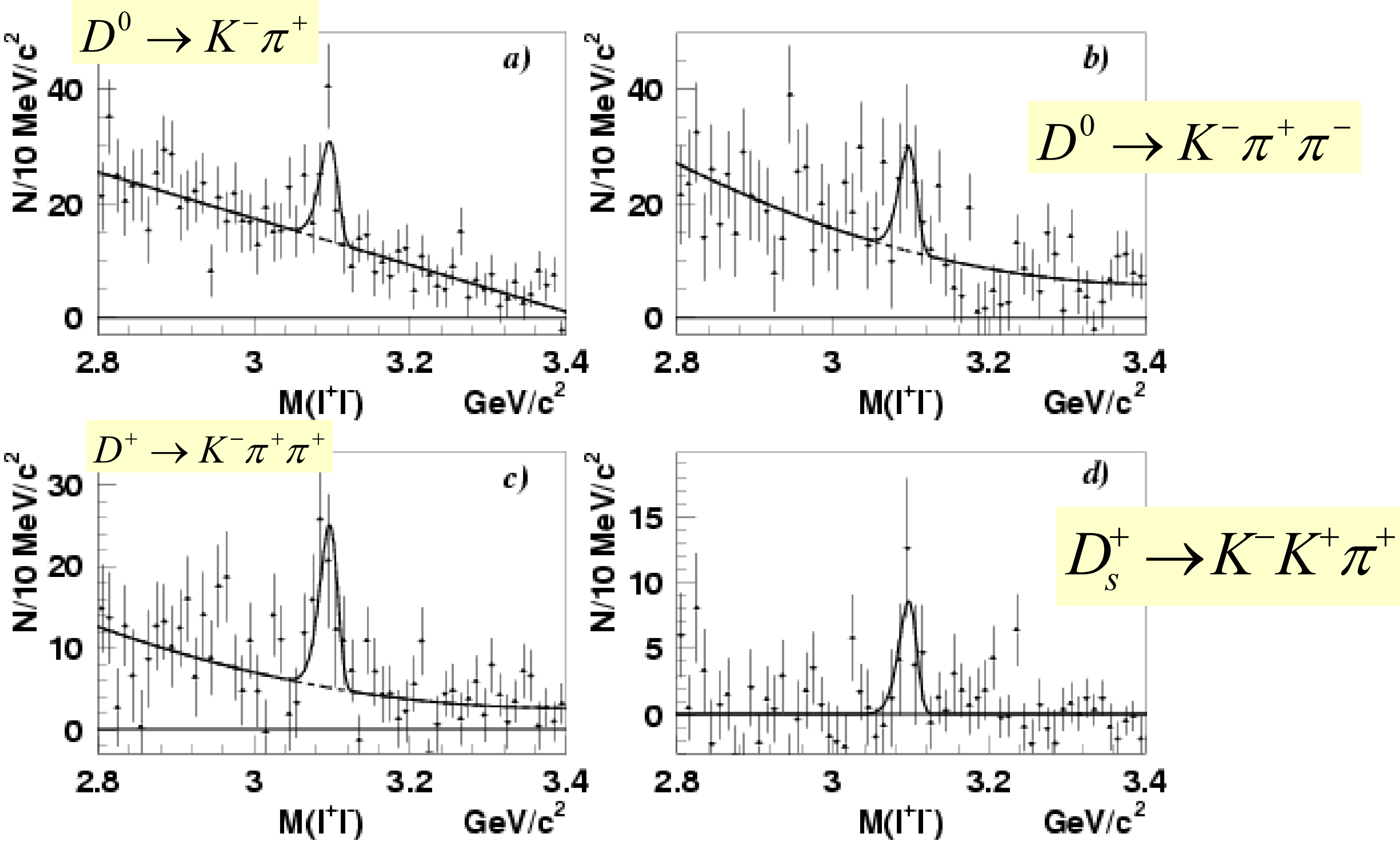


$$\sigma(e^+e^- \rightarrow J/\psi\eta_c) = 46 \pm 6^{+7}_{-9}\ \text{fb}$$

LO calculations: 2.31 ±1.09 fb

J/ψ production with associated charmed hadrons

BELLE
EPS-ID 562



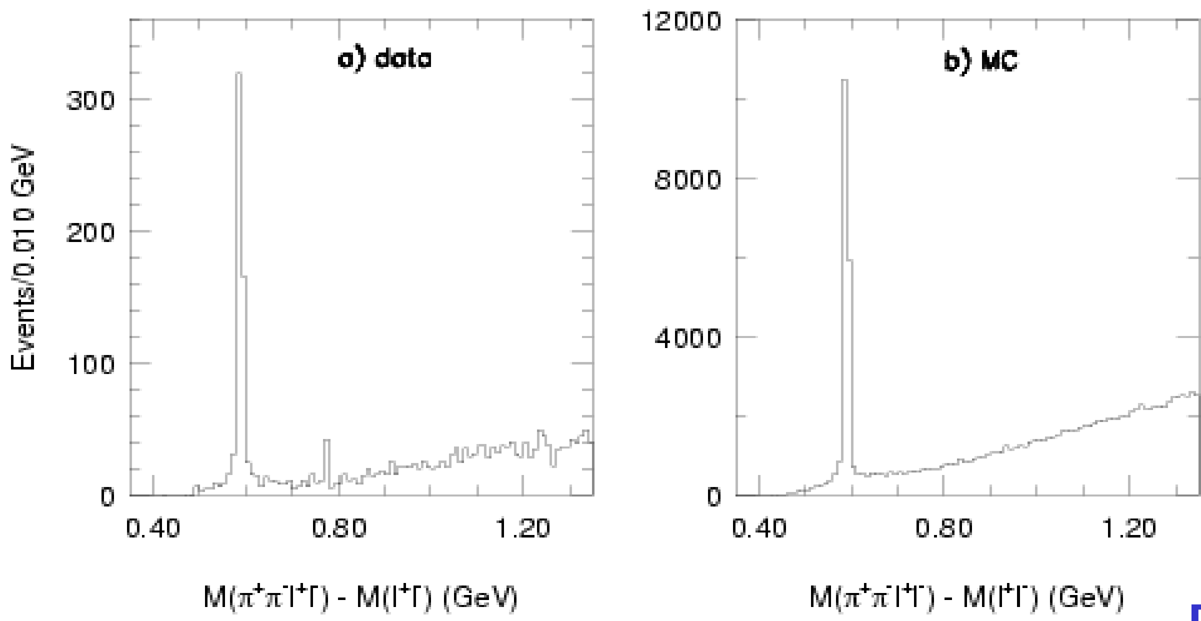
$P_{J/\psi}$>2.0 GeV/c

$$\sigma(e^+e^- \to J/\psi c\bar{c})/\sigma(e^+e^- \to J/\psi X) = 0.82 \pm 0.15 \pm 0.14$$

> 0.48 90% C.L.

NRQCD factorization: ~ 0.1

Observation of X(3872) State at BELLE



PRL 91(2003)262001

140 fb $^{-1}$

152M $\Upsilon(4S) \rightarrow BB$ decays

$B^{\pm} \rightarrow K^{\pm} J/\psi \pi^{+}\pi^{-}$

$X \rightarrow J/\psi \pi^{+}\pi^{-}$

$R_{B\psi(2S)} = 6.3 \pm 1.4\%$

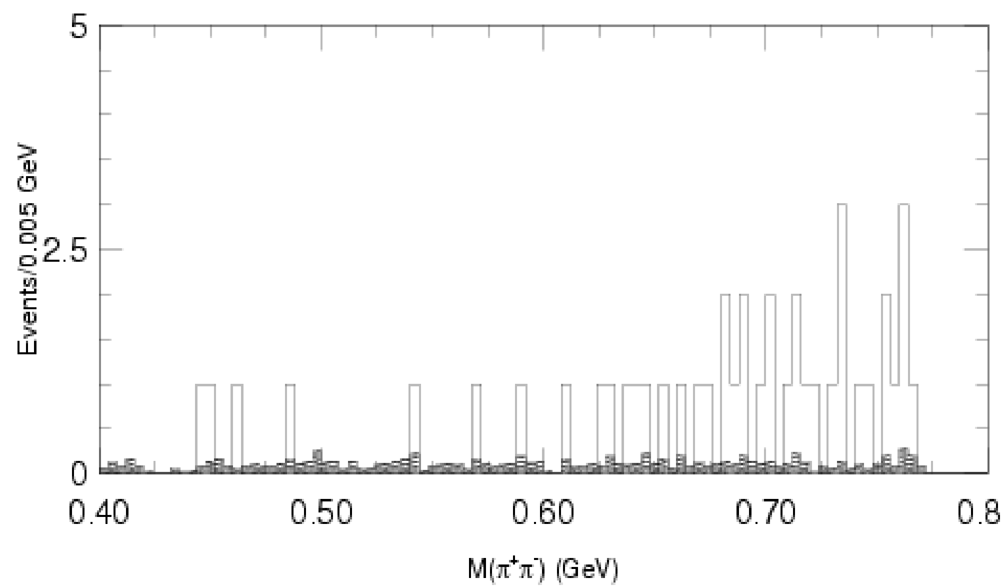
M = 3872.0 ± 0.6 (stat) ± 0.5 (syst) MeV

Width : 2.5 ± 0.5 MeV

489 ± 23 $\psi(2S)$ events

35.7 ± 6.8 X events

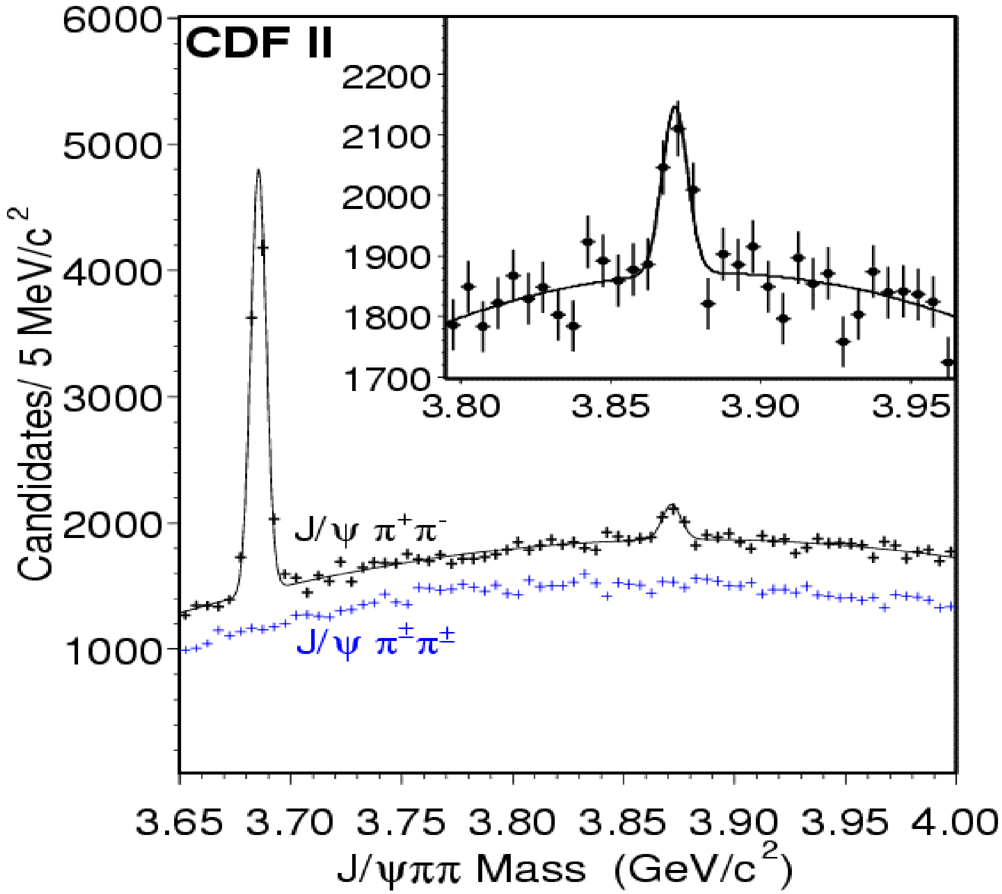
10.3 σ statistical significance



Vaia Papadimitriou (Fermilab)

Observation of X(3872) State at CDF

hep-ex/0312021



$X \rightarrow J/\psi \pi^+ \pi^-$

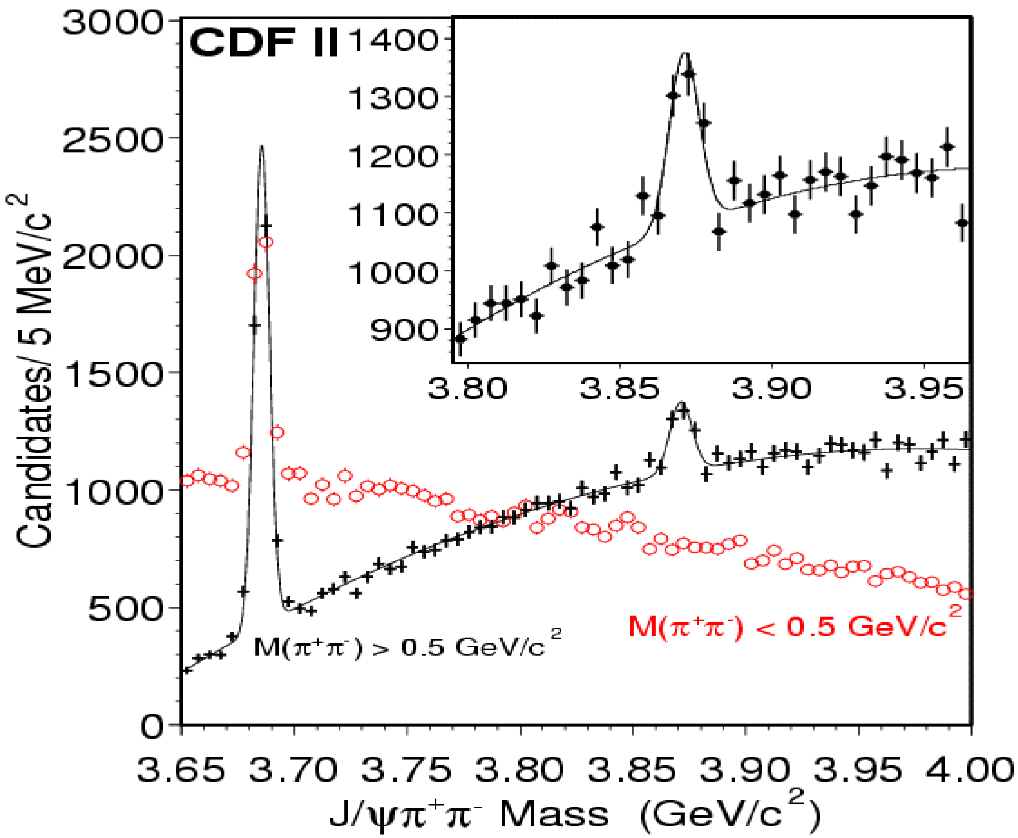
200 pb^{-1}

5790 ± 140 ψ(2S) events

580 ± 100 X events

X Width : 4.2 ± 0.8 MeV

Observation of X(3872) State at CDF



$X \to J/\psi\pi^+\pi^-$

$M_{\pi\pi} > 500$ MeV/c^2

3530 ± 100 $\psi(2S)$ events

730 ± 90 X events

11.6 σ statistical significance

$M_{\psi(2S)}$ = 3685.65 ± 0.09 (stat) MeV/c^2

$\psi(2S)$ Width : 3.44 ± 0.09 MeV/c^2

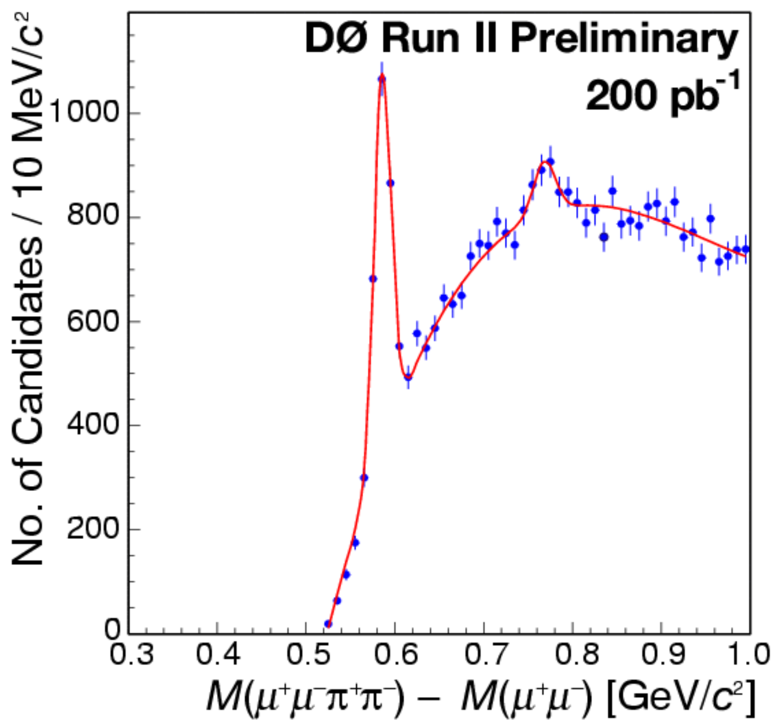
M_x = 3871.3 ± 0.7 (stat) ± 0.4 (syst) MeV/c^2

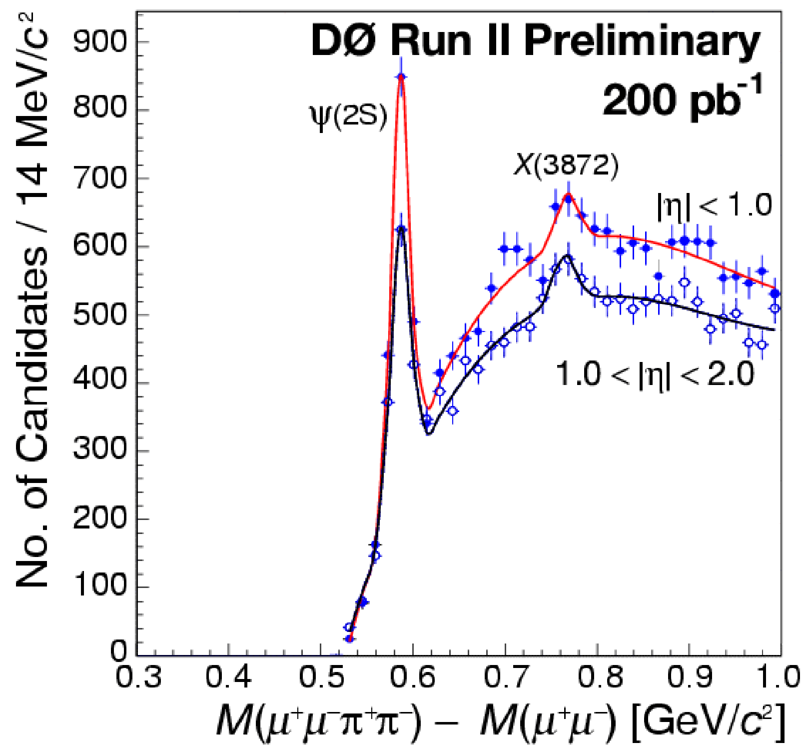
X Width : 4.9 ± 0.7 MeV /c^2

Observation of X(3872) State at D0

$M_{\pi\pi}$>520 MeV/c^2

$X \to J/\psi\pi^+\pi^-$





ΔM = 768.4 ± 3.5 (stat) ± 3.9 (syst) MeV/c^2

$\psi(2S)$ Width : 9.6 MeV/c^2

X Width : 12.2 MeV /c^2

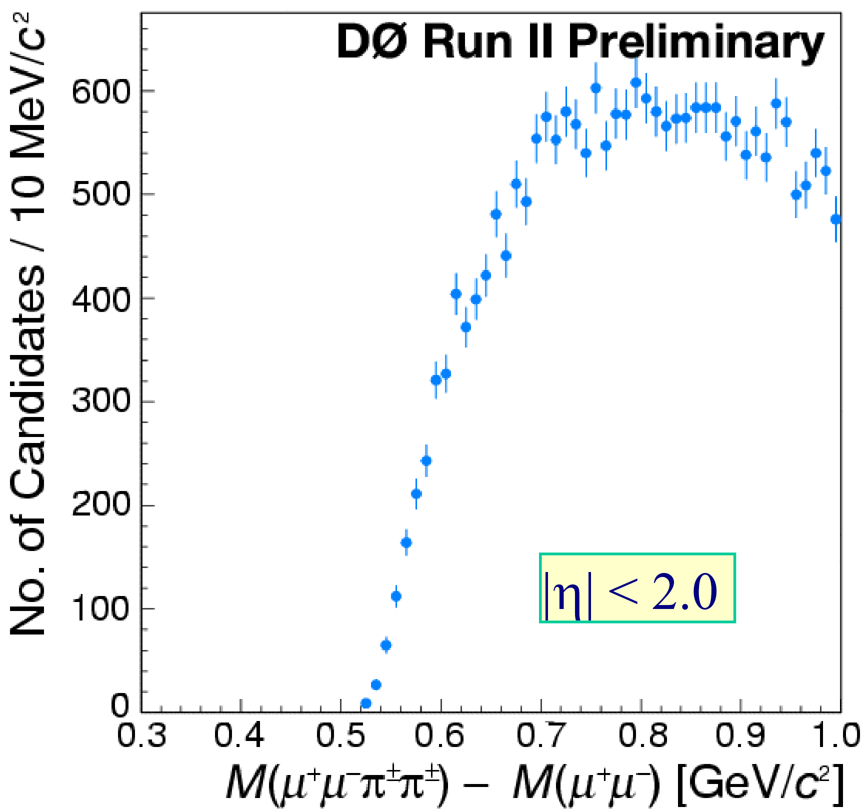
1700 ± 109 $\psi(2S)$ events

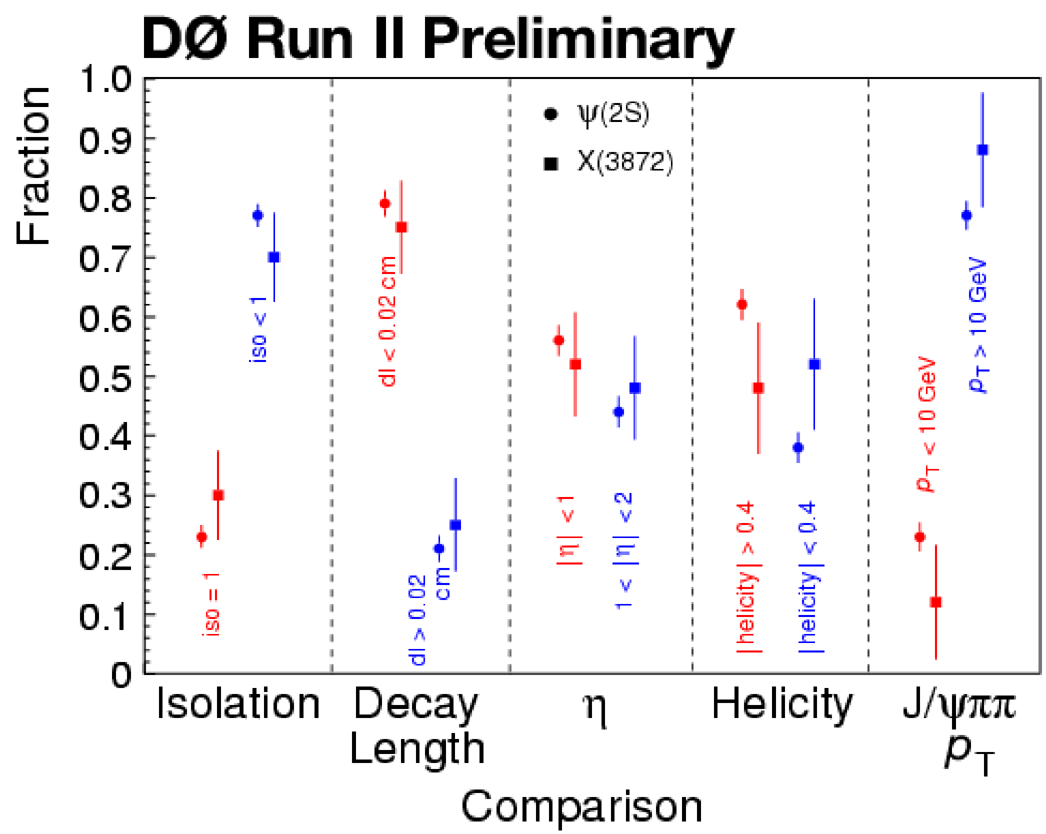
300 ± 61 X events

4.4 σ statistical significance

Observation of X(3872) State at D0

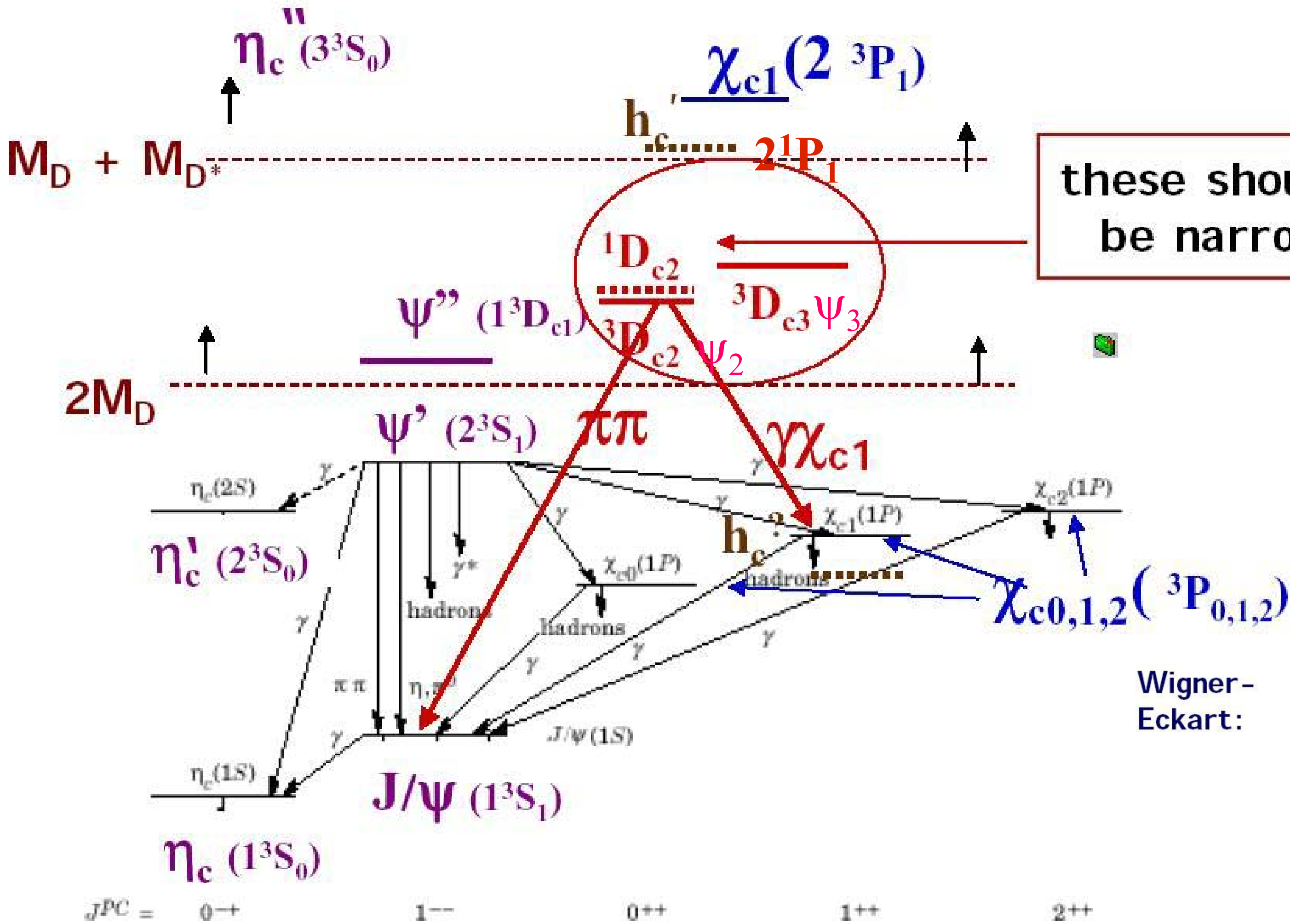
$X \rightarrow J/\psi\pi^+\pi^-$





Compare signal yield fractions for X(3872) and ψ(2S)

The Charmonium System



these should be narrow

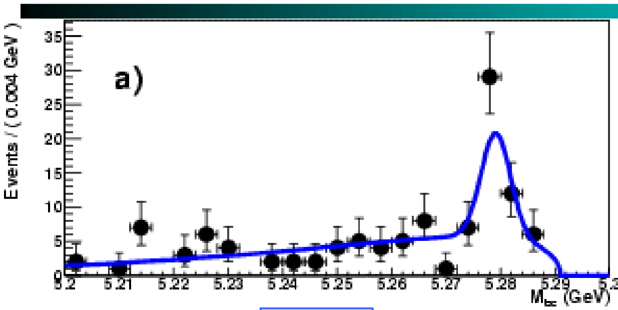
Wigner-Eckart: $\Gamma(\psi_2 \to \pi^+\pi^-\ J/\psi) = \Gamma(\psi_3 \to \pi^+\pi^-\ J/\psi) = \Gamma(\psi'' \to \pi^+\pi^-\ J/\psi)$

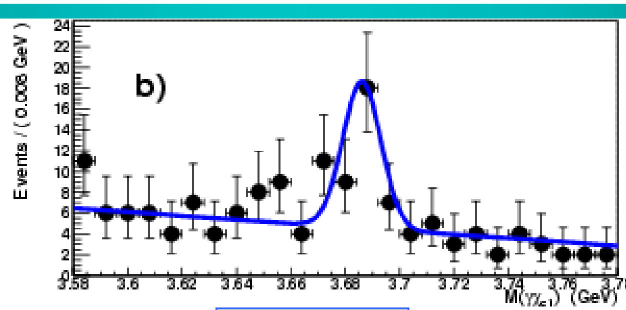
CLEO: < 55keV (90% CL)
BESII: 85 ± 35 keV (new)

$\Gamma(\psi_2 \to \gamma\chi_{c1})$ = 360 (207) keV >2 $\Gamma(\pi^+\pi^- J/\psi)$
$\Gamma(\psi_3 \to \gamma\chi_{c2})$ = 370 (299) keV >3 $\Gamma(\pi^+\pi^- J/\psi)$

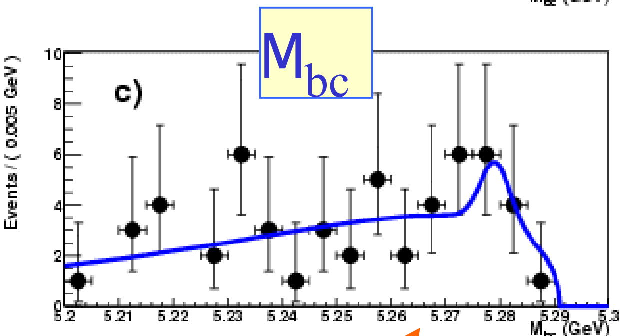
hep-ph/0311162 hep-ph/0401210

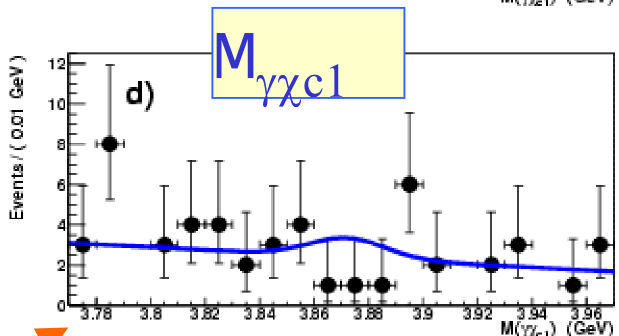
Search for X(3872) → $\gamma\chi_{c1}$($\gamma\chi_{c2}$) at BELLE





ψ(2S) region



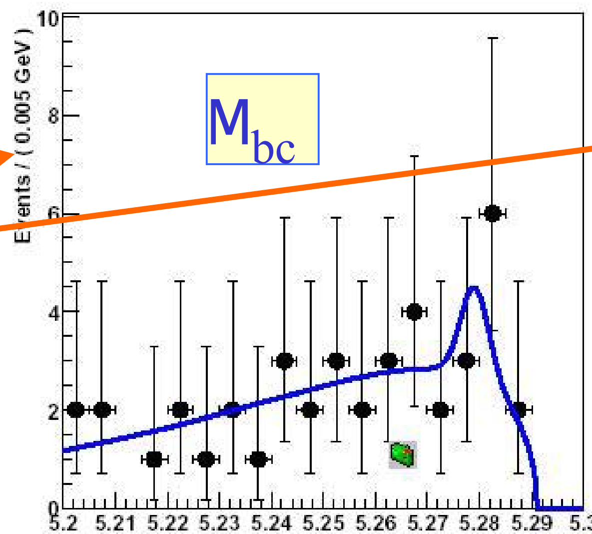


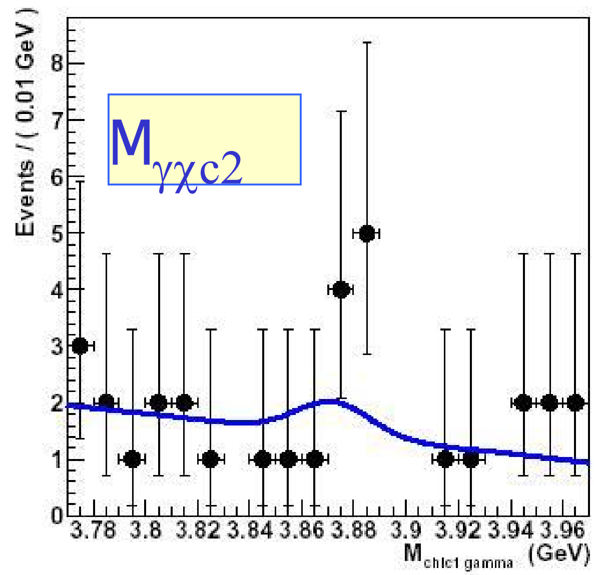
X(3872) region

$$\frac{\Gamma(X\to\gamma\chi_{c1})}{\Gamma(X\to\pi^+\pi^-J/\psi)} < 0.9$$

$$\frac{\Gamma(X\to\gamma\chi_{c2})}{\Gamma(X\to\pi^+\pi^-J/\psi)} < 1.1$$

No signals!





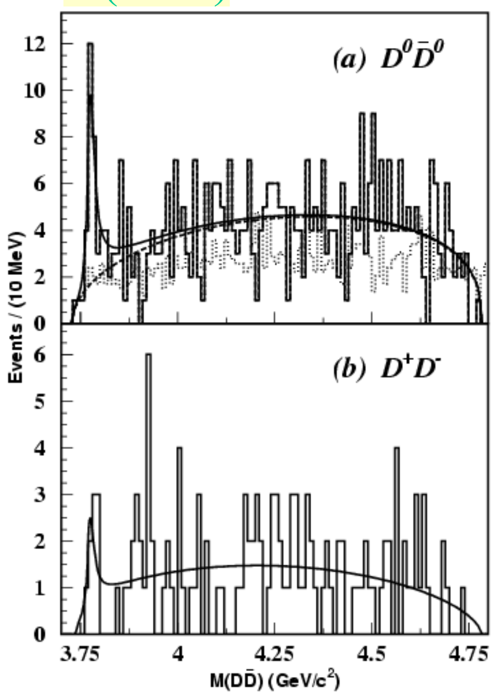
Contrary to expectations for charmonium D states

Search for X(3872) → DD (BELLE)

88 fb^{-1}

hep-ex/0307061

Ψ(3770)



$B^{\pm} \rightarrow \mathbf{K}^{\pm} D^0 \overline{D}^0$

$B^{\pm} \rightarrow \mathbf{K}^{\pm} D^+ D^-$

Br($B^{\pm} \rightarrow$ **X(3872)K**$^{\pm}$) x Br(X →)

$< 6 \times 10^{-5}$ at 90%C.L.

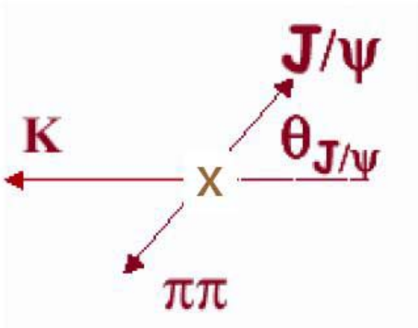
Br($B^{\pm} \rightarrow$ **X(3872)K**$^{\pm}$) x Br(X → $\mathbf{D^+D^-}$)

$< 4 \times 10^{-5}$ at 90%C.L.

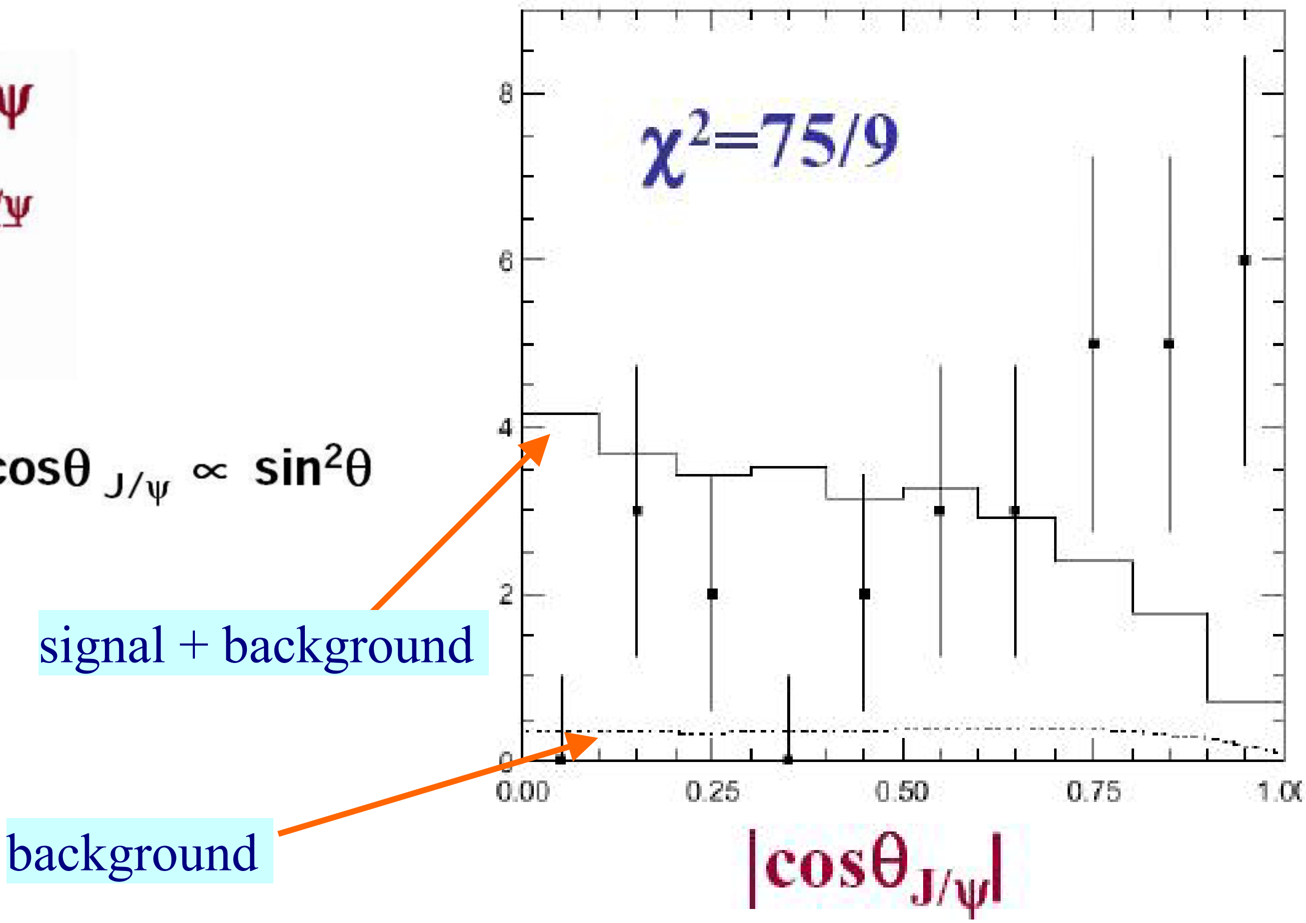
Br($B^{\pm} \rightarrow$ **X(3872)K**$^{\pm}$) x Br(X → π^0)

$< 6 \times 10^{-5}$ at 90%C.L.

J/ψ helicity distribution and $h_c{}'(1^{+-})$ - BELLE



For 1^{+-} expect: $dN/d\cos\theta_{J/\psi} \propto \sin^2\theta$



$h_c{}'(1^{+-})$ very unlikely

Is the X(3872) the 2^3P_1 State? (BELLE)

Expectation:

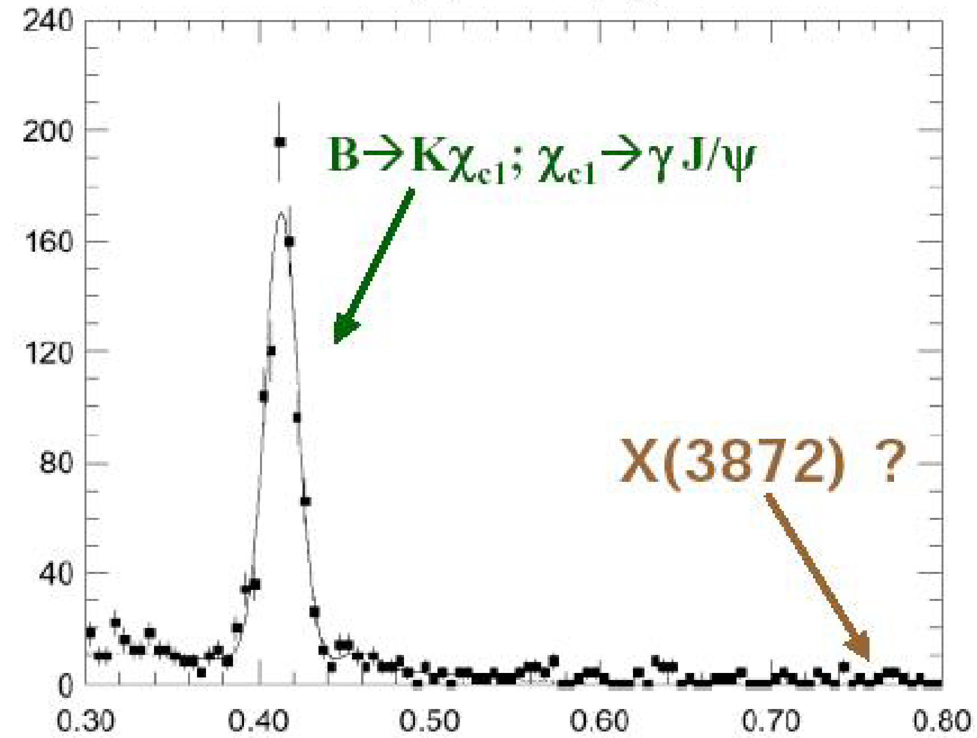
Barnes, Godfrey hep-ph/0311162

$$\frac{\Gamma(2^3P_1 \to \gamma J/\psi) \sim 11\ \text{keV}}{\Gamma(2^3P_1 \to \pi\pi J/\psi) \sim \Gamma(\psi' \to \pi^0 J/\psi) \sim O\ (0.3\ \text{keV})} \sim 30$$

isospin violating

$\Gamma(\gamma J/\psi)$ too small

$M(\gamma J/\psi)$



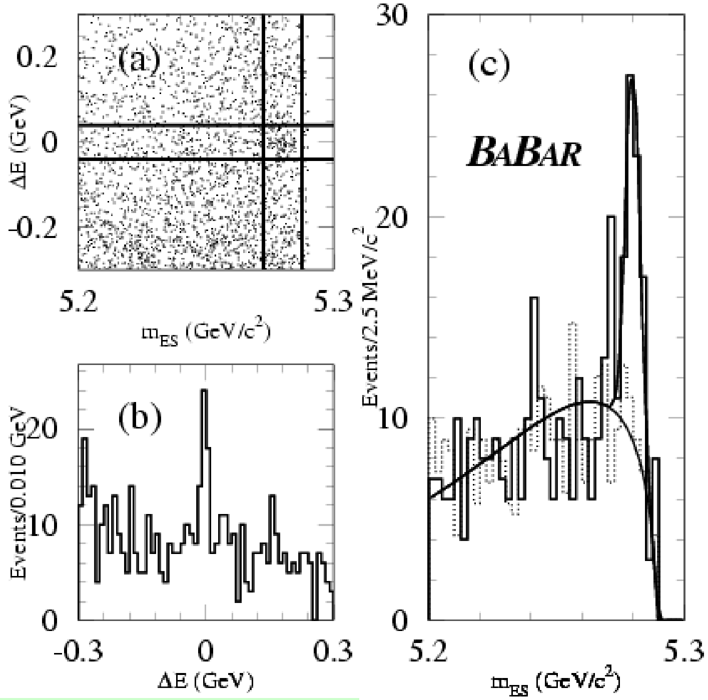
$$\frac{Br(X \to \gamma J/\psi)}{Br(X \to \pi^+\pi^- J/\psi)} < 0.4$$

Search for X(3872) → J/ψη (BABAR)

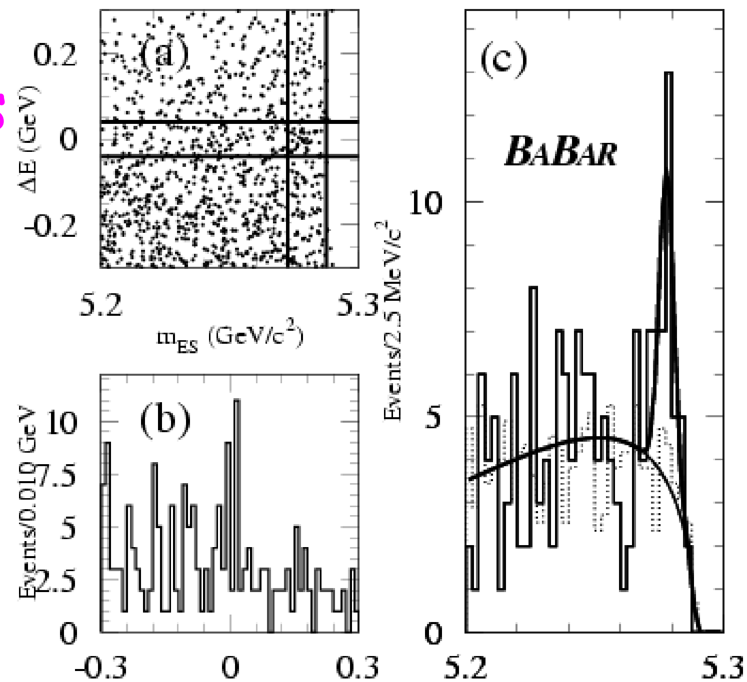
81.9 fb^{-1}

90M Υ(4S) → BB decays

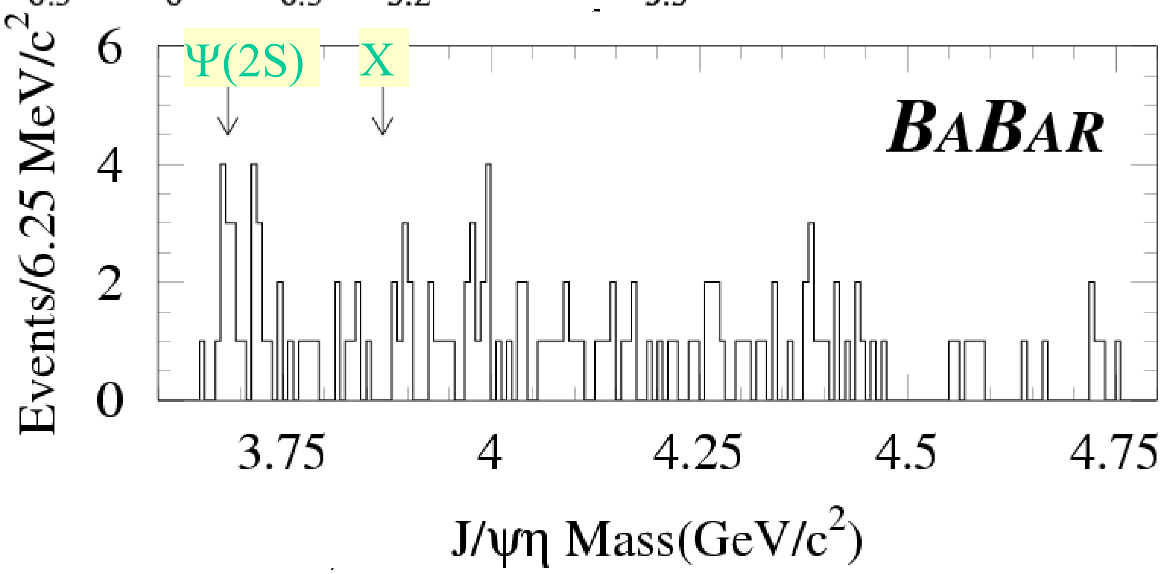
hep-ex/0402025



$B^{\pm} \to J/\psi\eta K^{\pm}$



$B^0 \to J/\psi\eta K^0_s$



$Br(B^{\pm} \to$ **X(3872)K**$^{\pm}$, $X \to J/\psi\eta)$

$< 7.7 \times 10^{-6}$ at 90%C.L.

Conclusions

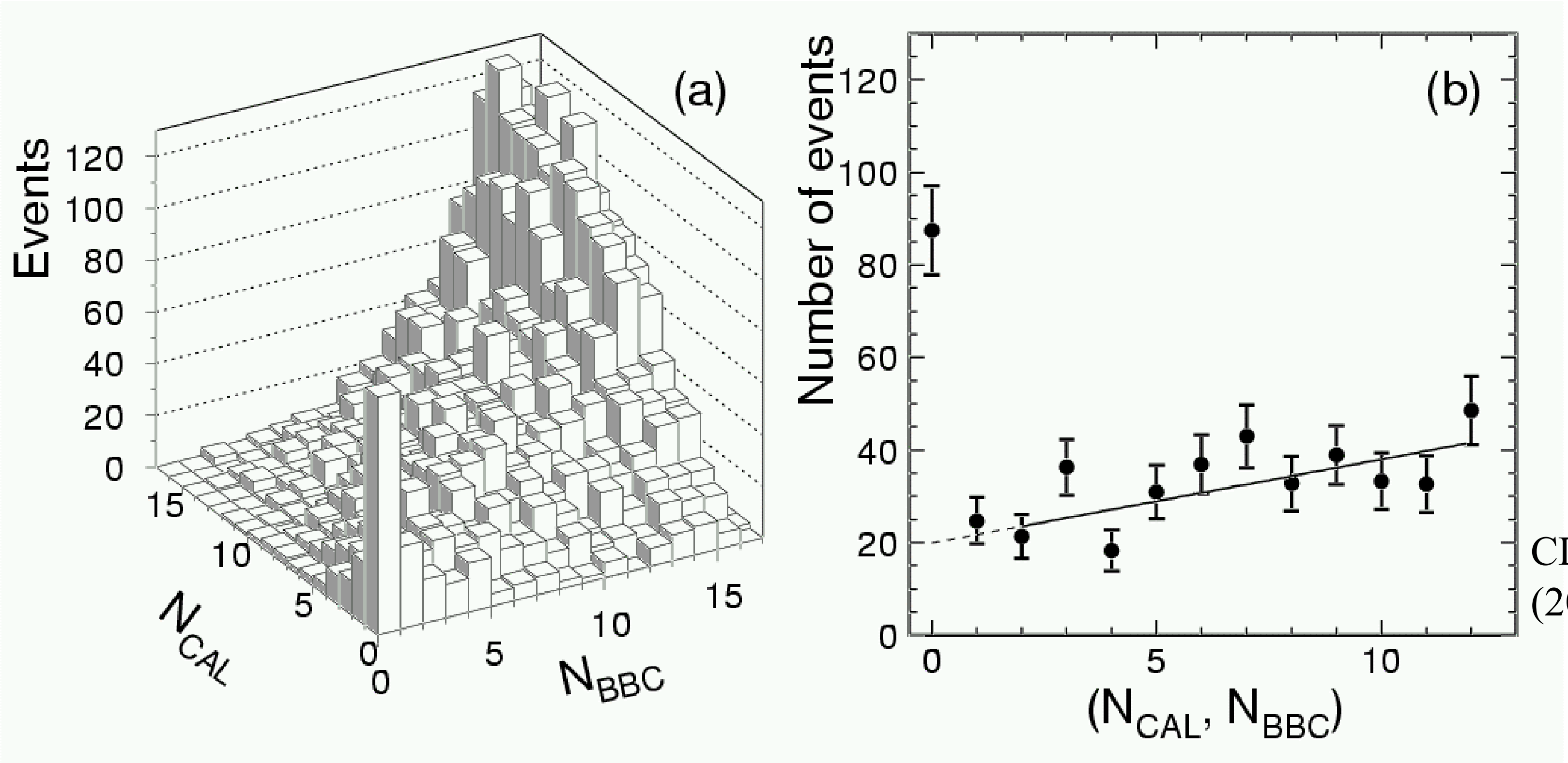
- Lots of results, many surprises
- Very fruitful interaction between theory and experiment
- Tevatron Run II expected to provide (4.4-8.5) fb^{-1} by October 2009
- HERA-II expected to deliver 0.75 fb^{-1} equally distributed over charges and helicities by end of 2007. Particular effort will be made to reach 1 fb^{-1}
- BELLE is expected to have 500 fb^{-1} by the end of 2006; 1 ab^{-1} by the end of 2008 (~1B BBbar pairs)
- BABAR is expected to have 500 fb^{-1} by the end of 2006
- A lot of answers and surprises awaiting!!

Backup Slides

BACKUP SLIDES

Diffractive J/ψ Production

- Use Beam-Beam-Counters and forward calorimeter towers to "tag" diffractive events (gap in $2.4 < |\eta| < 5.9$)

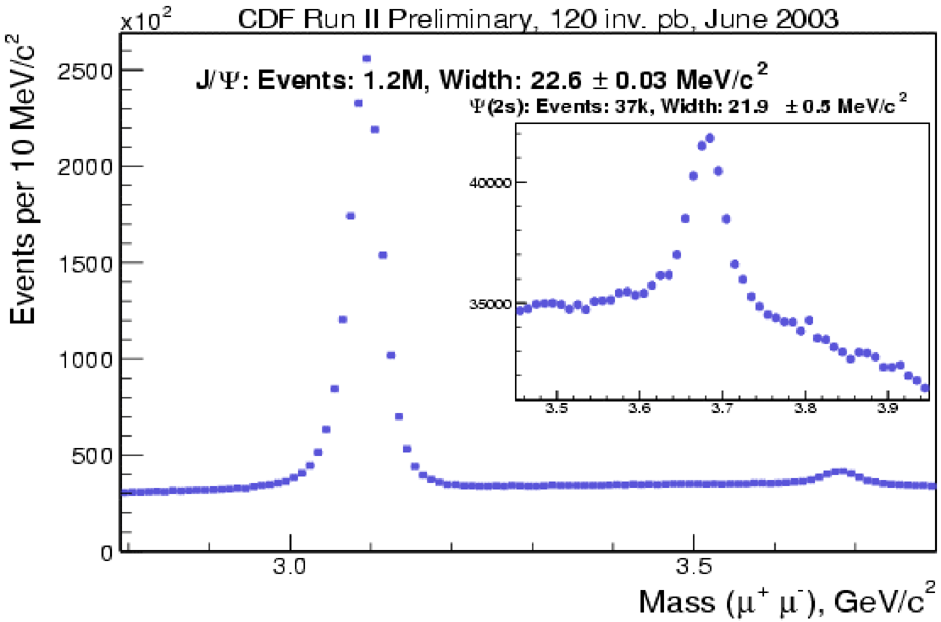


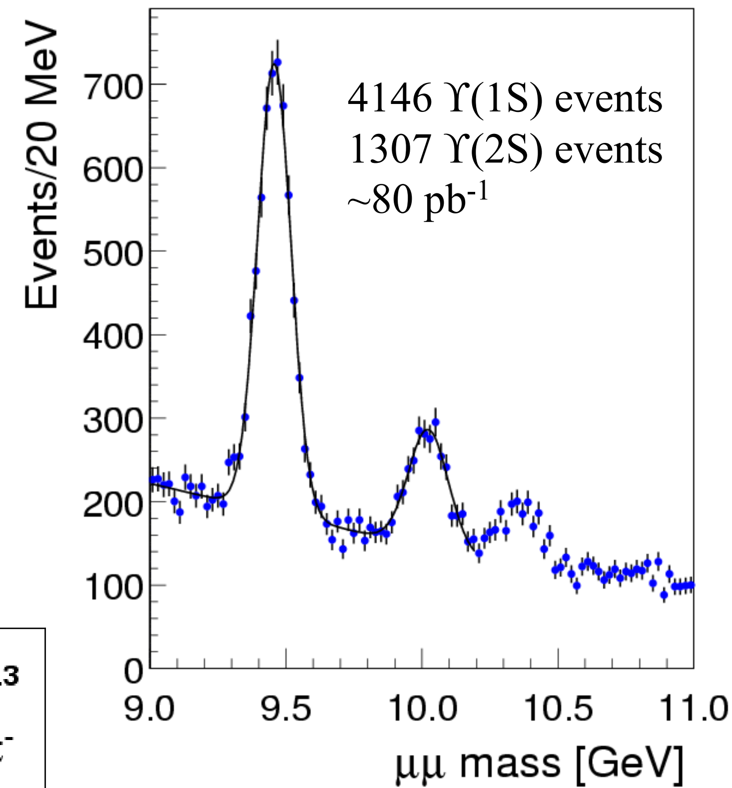
$|\eta_\psi| < 1.0$

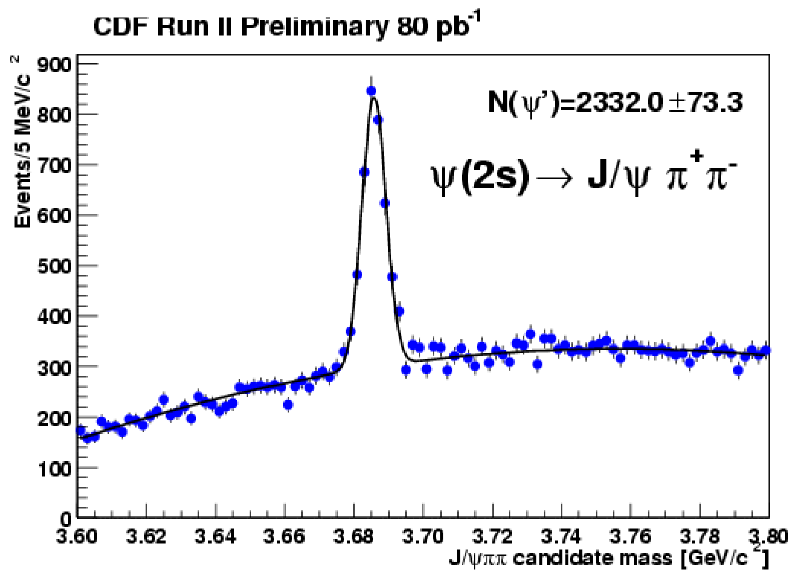
CDF, PRL 87 (2001) 251803

Ratio of diffractive to total production rate: $R_\psi = 1.45 \pm 0.25$ %

Run II - CDF



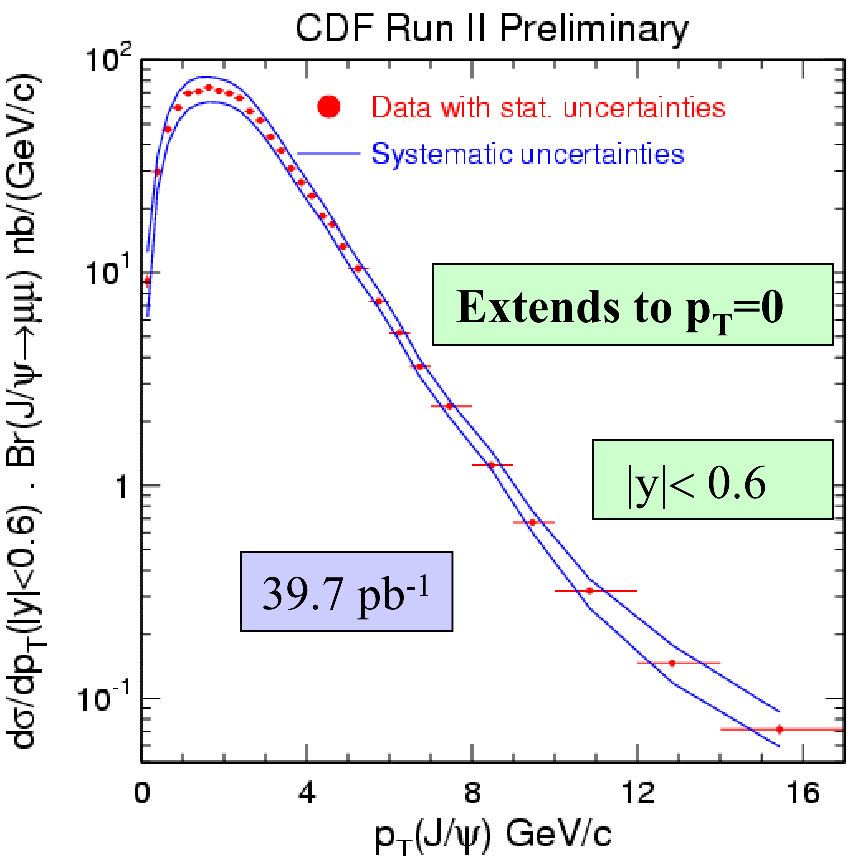


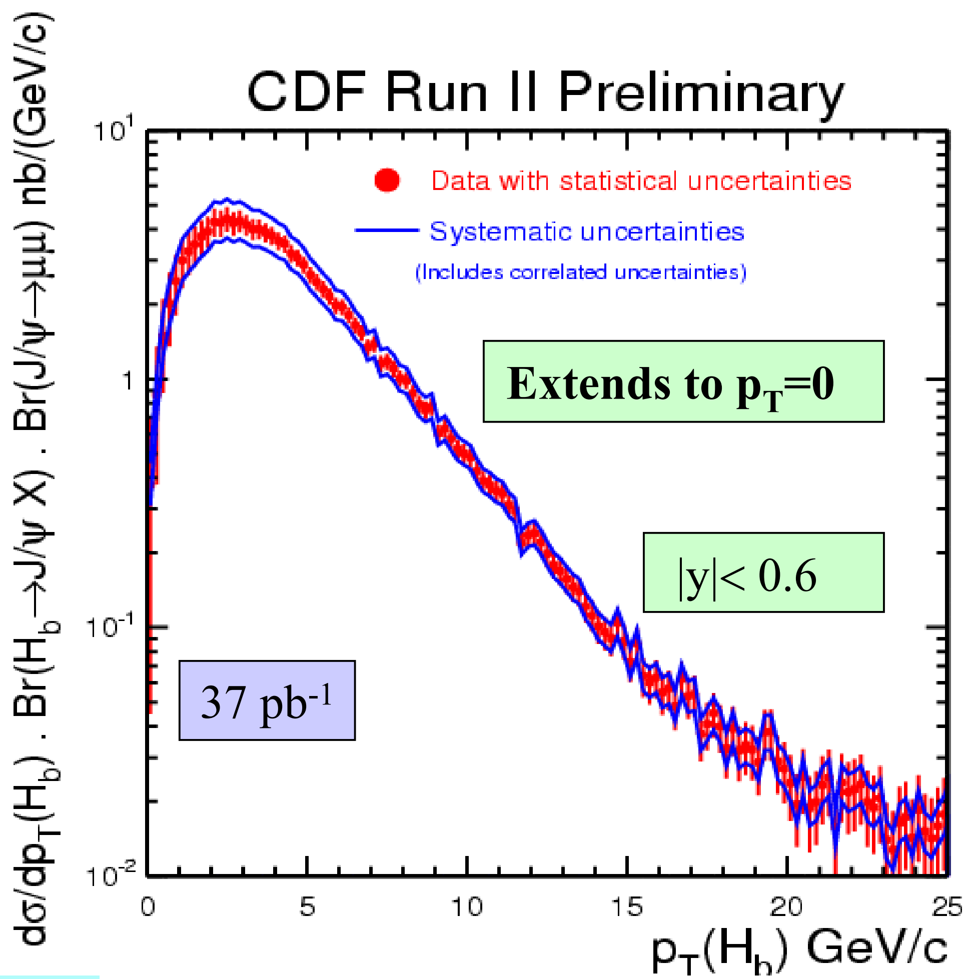


All four tracks in silicon

3.5 MeV/c^2 resolution →

J/ψ Cross Section – Run II (CDF)





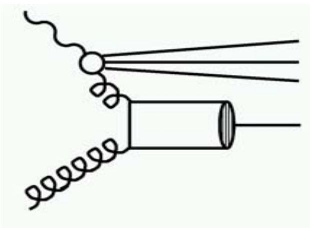
$$\sigma_{p\bar{p}\to J/\psi} = 240 \pm 1(stat)^{+35}_{-28}(syst)nb$$

$$\sigma(p\bar{p} \to H_b X, |y| < 0.6) Br(H_b \to J/\psi X) Br(J/\psi \to \mu\mu) =$$

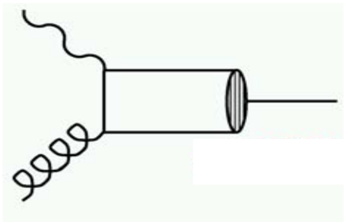
$$24.5 \pm 0.5(\text{stat}) \pm 4.7(\text{syst})\text{nb}$$

HERA Production Mechanisms

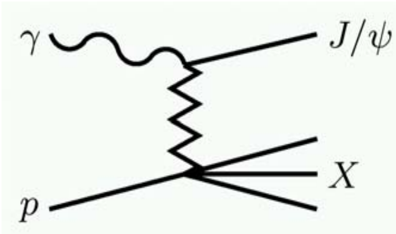
Inelastic | **p-dissociation** | **Elastic**

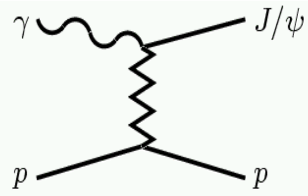


“resolved” (gg-fusion)
(z<0.3)



direct (γg-fusion)
(z>0.3)





J/ψ from ψ(2S) decays (ψ(2S) → J/ψππ and others)
(not subtracted, measured, ~ 15%)

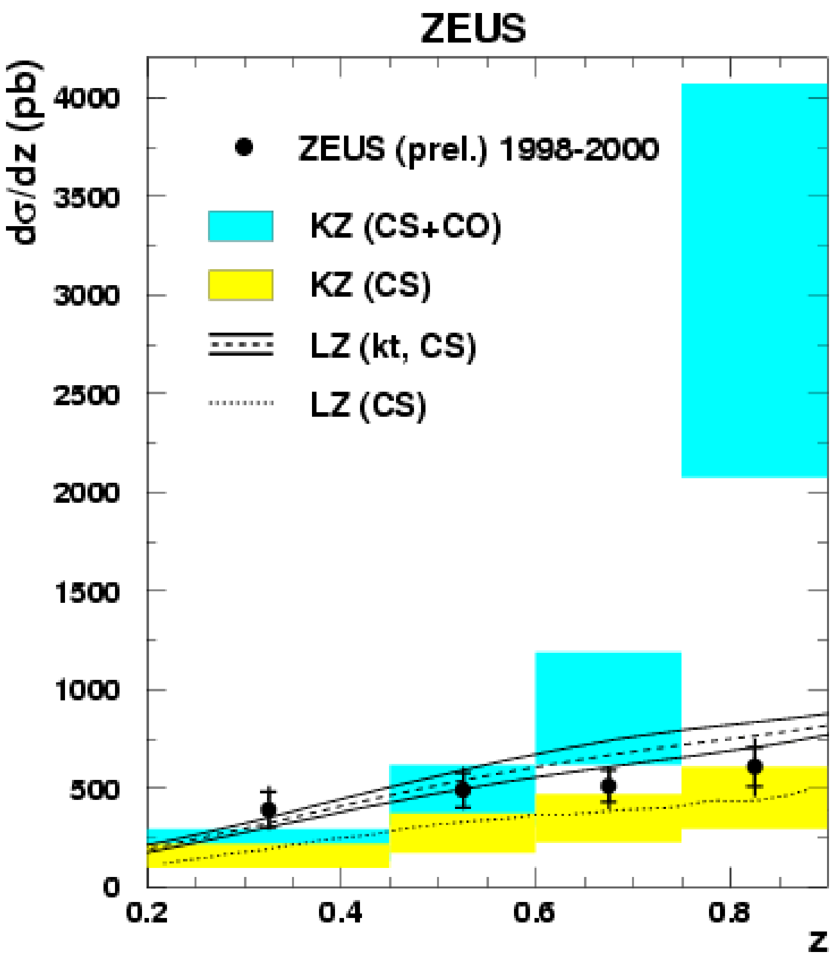
J/ψ from χ_c decays (not subtracted)
(1% of inelastic, up to 7% at lowest z)

J/ψ from B decays (not subtracted)
(5% of inelastic, up to 25% at lowest z)

Cut on z, (fwd.) energy,
add'l tracks, ...

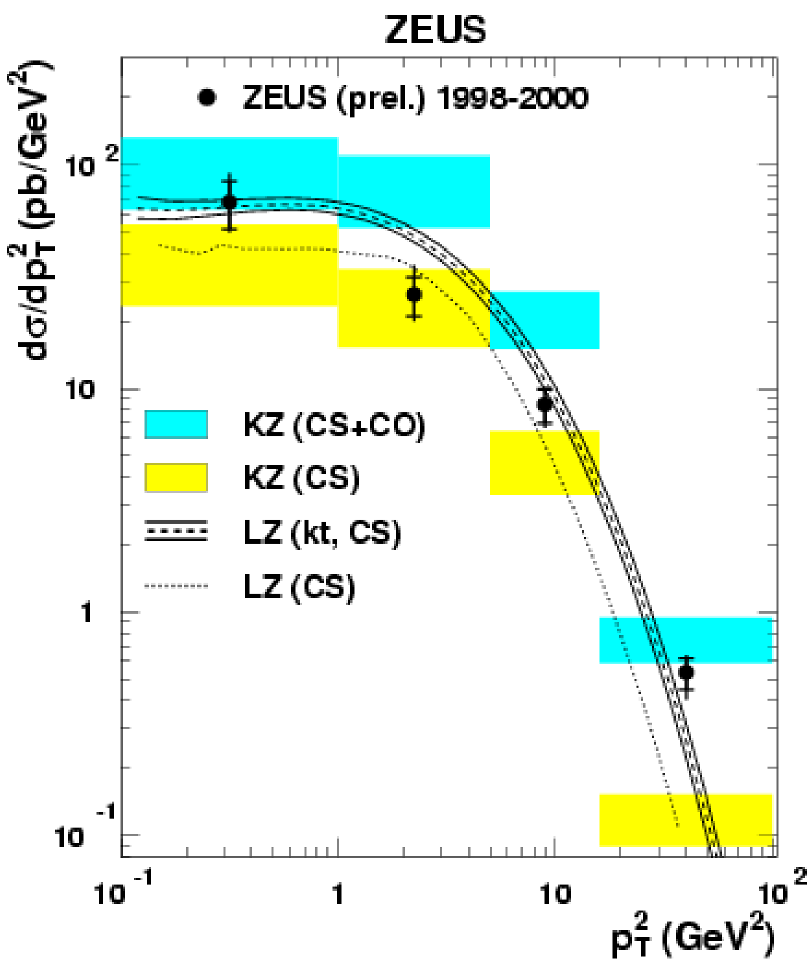
“Forward tagging”

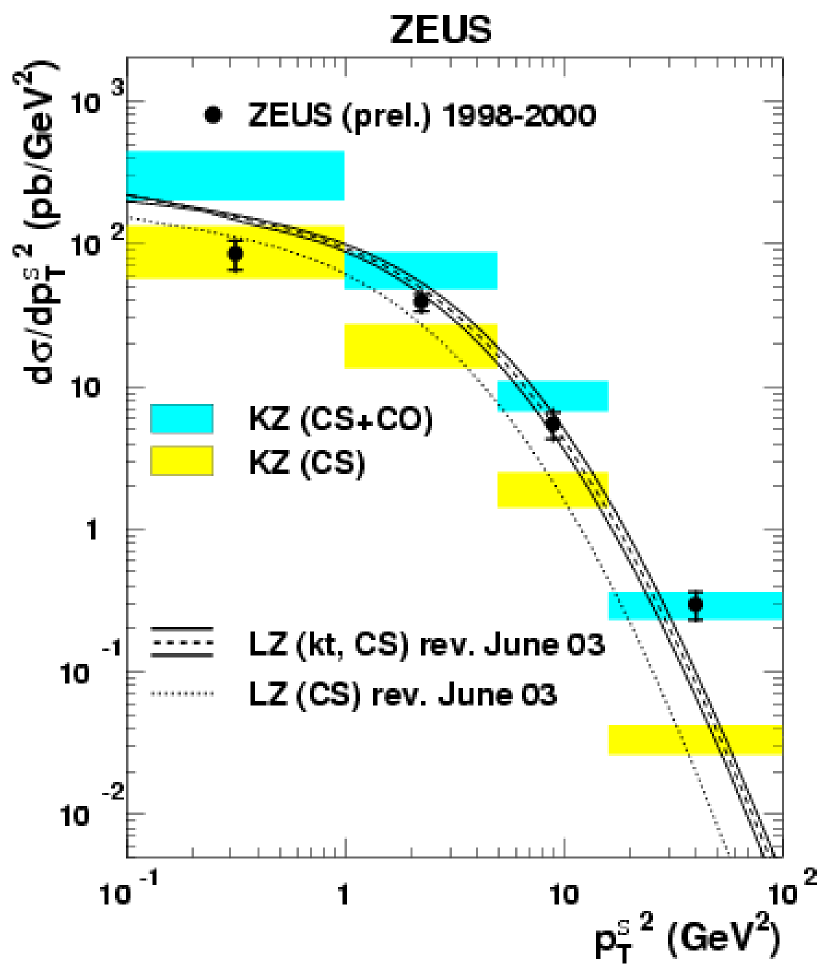
Zeus - J/ψ Electroproduction: inelasticity



- KZ(CS+CO): too high at large z values (high-z resummation needed?)
- CS predictions are consistent with data

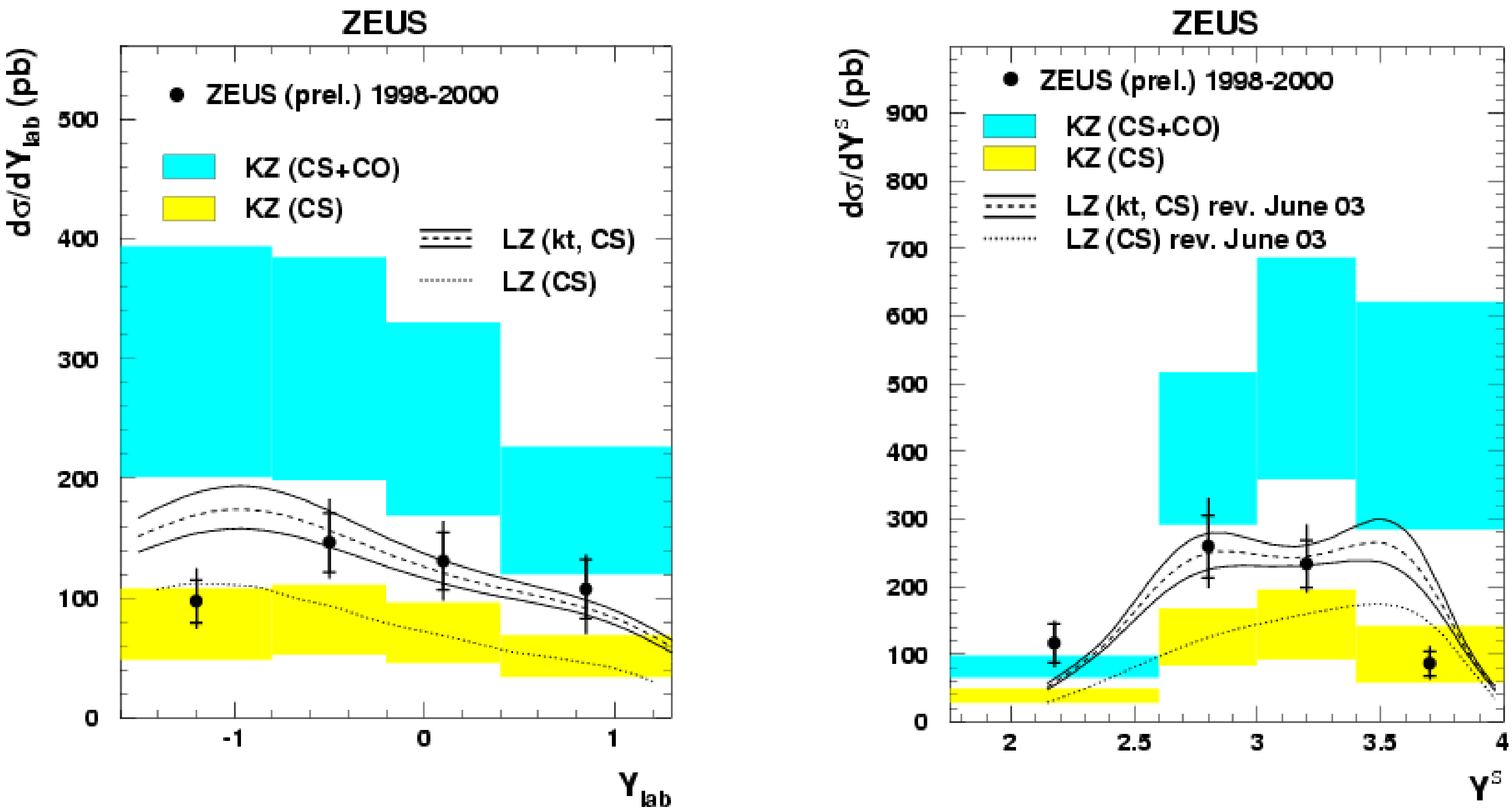
Zeus - J/ψ Electroproduction: p_T^2 and p_T^{*2}





KZ (CS) and LZ(CS): too soft in comparison to data
KZ (CS+CO): overshoots data at low p_T^* values
LZ (kt, CS): too soft as well (NLO corrections?)

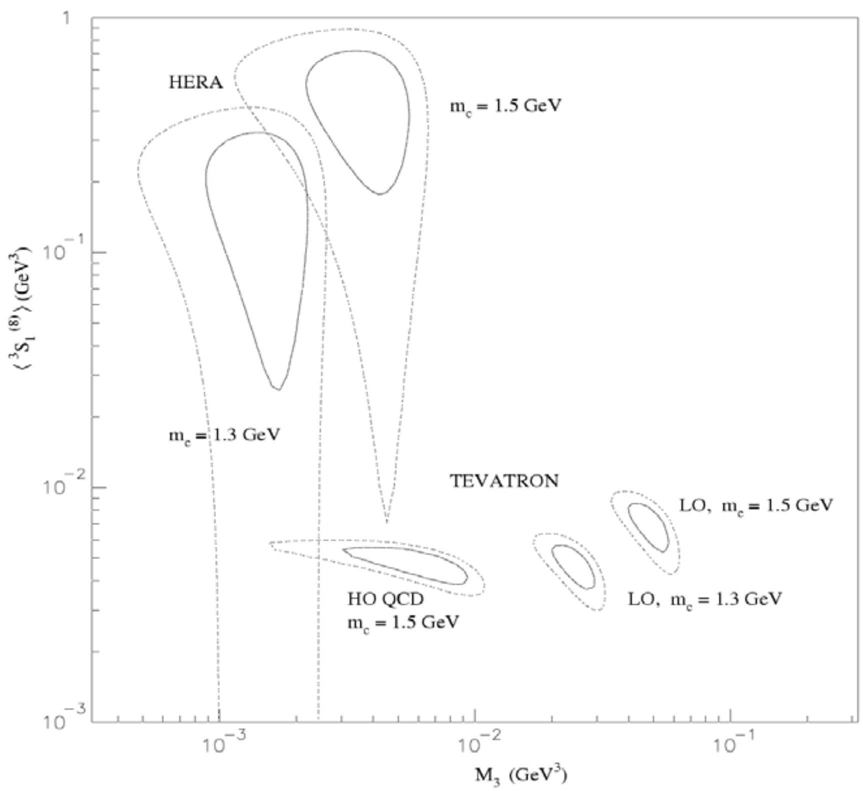
Zeus - J/ψ Electroproduction: rapidity



LZ (kt, CS) tends to be above the data in photon direction

HERA vs. Tevatron ME

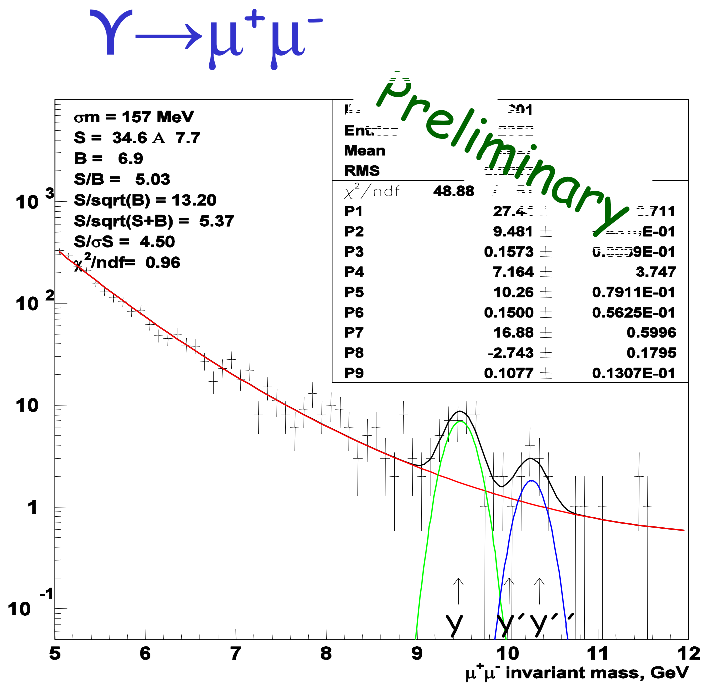
- Only use theoretically safe regime: p_T^2, $Q^2 > 4$ GeV^2, $M_X > 10$ GeV
  - Statistics limited in 1999
- Consistent description difficult
- Repeat including recent data?
- Common fit?

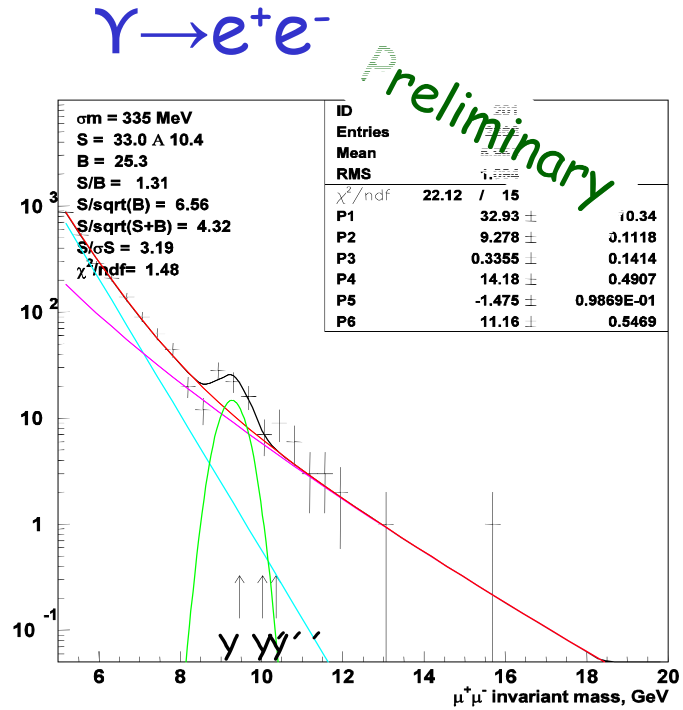


$< {}^1S_0^{(8)} > + 3/m_c^2 < {}^3P_J^{(8)} >$

J.K.Mizukoshi,
hep-ph/9911384

Upsilon Production : σ(pA→ ϒ)





Existing measurements by

E605, E771

contradictory

\# ϒ events 35 ± 8
Width 157 MeV

\# ϒ events 33 ± 10
Width 335 MeV

Width : in agreement with MC

Measurement of the ϒ production cross section is feasible
may help to distinguish between Fermilab fixed target measurements

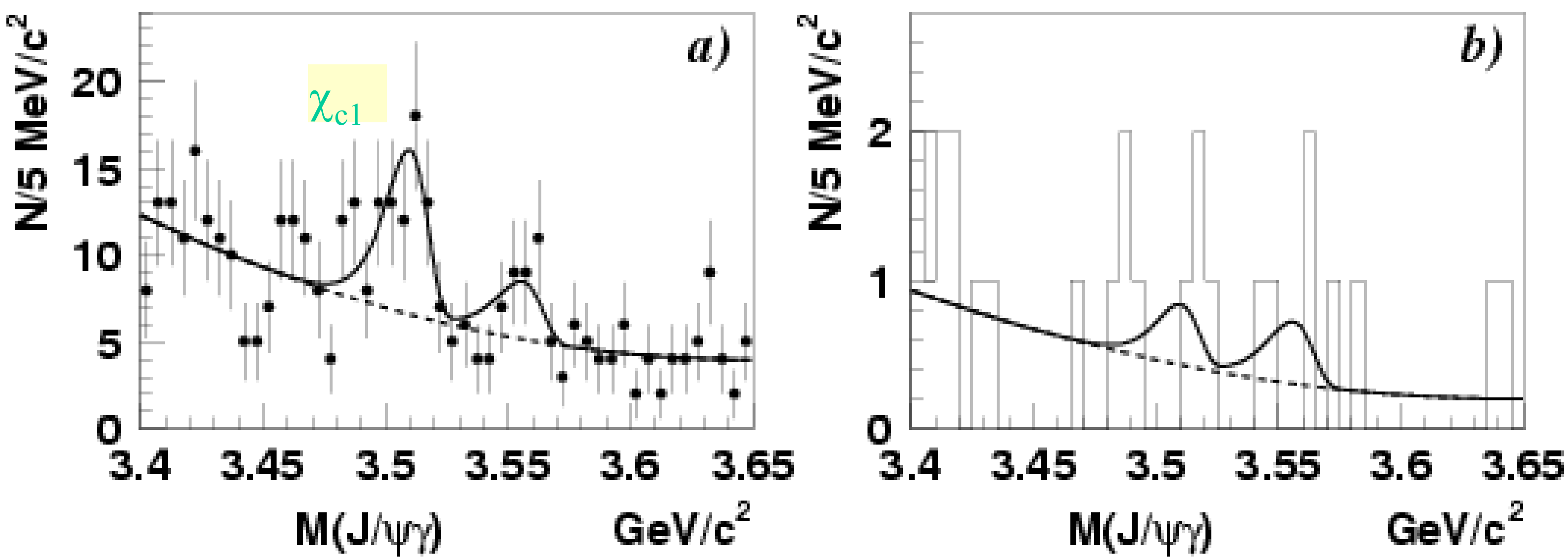
Prompt $\chi_{c1(2)}$ production at BELLE

$e^+e^- \rightarrow \chi_{c1(2)}$ X

PRL 89 (2002)142001
EPS-ID 562

101.8 fb $^{-1}$

$2.8 < M_{recoil}(J/\psi\gamma) < 3.8$



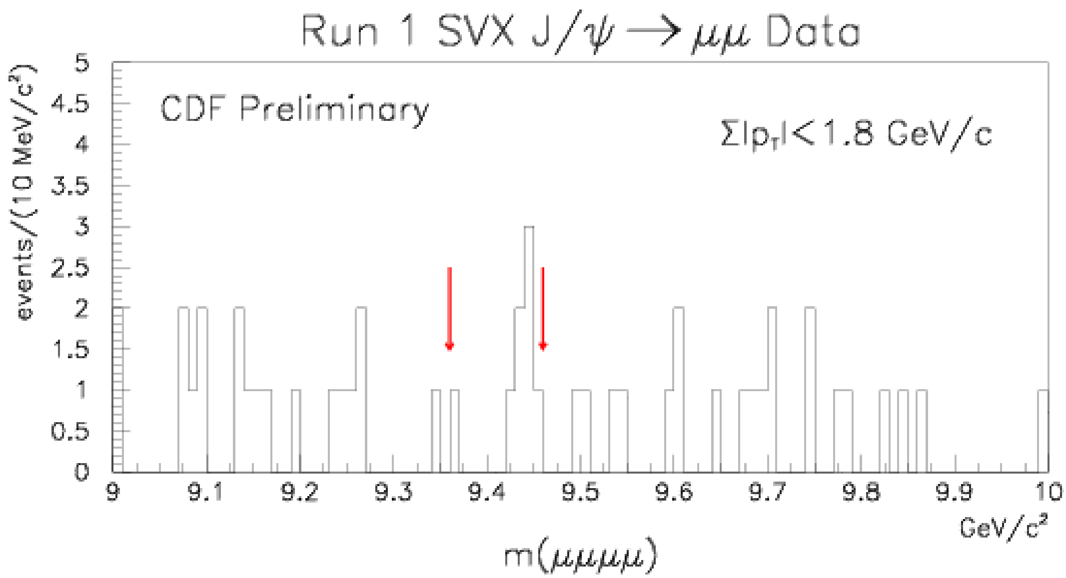
Search for η_b at CDF

$\eta_b \to J/\psi\ J/\psi$ reconstruction

Braaten, Fleming, Leibovich
PRD 63 (2001) 094006

Expected production rate:
$\sigma(\eta_b) \sim (3\text{-}6) \times \sigma(\Upsilon(1S))$
$B(\eta_b \to J/\psi\ J/\psi) \sim 7 \times 10^{-4\pm1}$

100 pb^{-1}
Possibly seen in Run I?



Small cluster: 7 events, 1.8 events expected from background

CDF mass resolution ~ 10 MeV/c^2
Search window 9.36 to 9.46 GeV/c^2
Simple mass fit: 9445 ± 6(stat) MeV/c^2
Probability of background fluctuation: 1.5% (~2.2 σ)

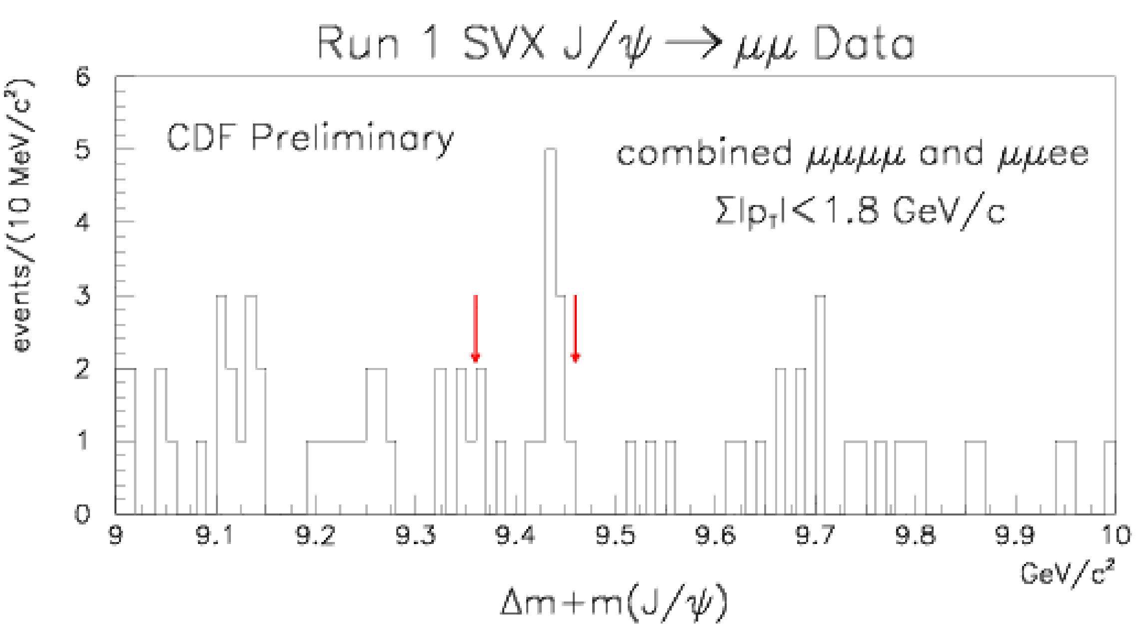
Search for η_b at CDF

$\eta_b \rightarrow J/\psi\ J/\psi$ reconstruction

Rate Limit:

$\sigma\eta_b(|y|<0.4)\ B(\eta_b \rightarrow J/\psi\ J/\psi)\ [B(J/\psi \rightarrow \mu\mu)]^2 < 18$ pb

Central value 3.5 pb



Improves apparent significance
Supportive of signal hypothesis
Need more data for confirmation