Quarkonia Production with Leptons and Hadrons

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CDF II

DØ

E866/NuSea

H1

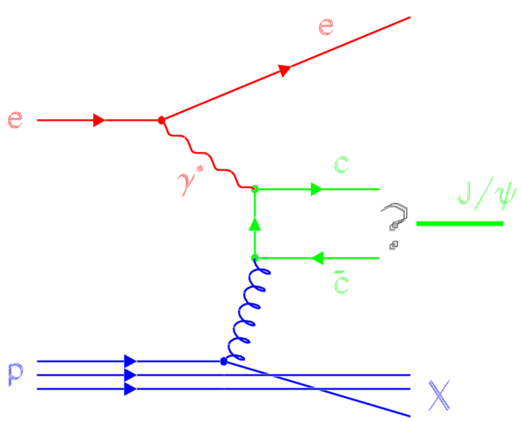
ZEUS

HERA B

- Introduction
- FNAL - past, present, and future
  - Tevatron (Run I/Run II): (J/ψ, $\psi(2S)$, χ_c, Υ, χ_b, η_b)
  - Fixed Target: (Υ polarization)
- HERA - past, present, and future
  - Inelastic production measurements (J/ψ, $\psi(2S)$)
  - Diffractive production measurements (J/ψ)
  - Fixed Target: (J/ψ, ψ (2S), χ_c, Υ)
- Conclusions

Introduction

- ***Tevatron (Run I 1992-96, $\int L\,dt = 20\ pb^{-1}$ (IA) + $90\ pb^{-1}$ (IB)):***
  - ***p → ← pbar at $\sqrt{s} = 1.8$ TeV***
  - ***η, p_T, polarization***
- ***HERA ("Run I" , $\int L\,dt = 100\ pb^{-1}$):***
  - ***$e^{\pm}$ (27.5 GeV) → ← p (820/920 GeV) at $\sqrt{s} = 300/320$ GeV***
  - ***Q^2, W, z, p_T, t, ..., polarization***
  - ***overconstrained kinematics***
- ***History***
  - ***Inelastic J/ψ production at HERA: a golden way to extract gluon density***
  - ***Elastic/diffractive J/ψ production to measure luminosity***
- ***Variety of presumed production mechanisms:***
  - ***Diffractive/elastic***
  - ***Gluon-gluon-fusion, photon-gluon-fusion***
  - ***Gluon fragmentation***
  - ***"Resolved photon"-gluon/quark-fusion***
  - ***+ decays***



Publications (Most Recent Only)

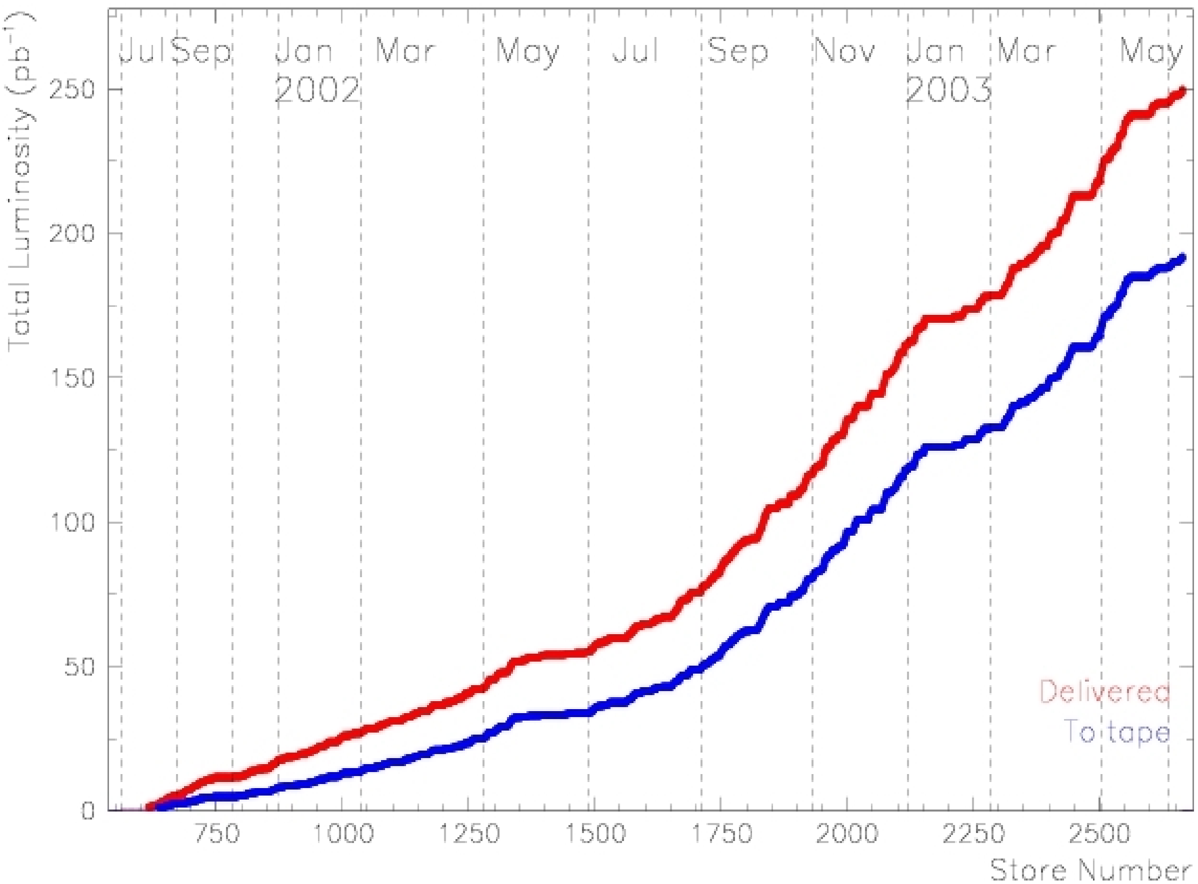
TEVATRON

J/ψ and $\psi(2S)$ cross section	CDF	(15 pb^{-1})	PRL 79 (1997) 572
J/ψ cross section, $\chi_c \to J/\psi\gamma$	D0	(7 pb^{-1})	PL B370 (1996) 239
$\chi_c \to J/\psi\gamma$	CDF	(18 pb^{-1})	PRL 79 (1997) 578
χ_{c1}/χ_{c2}	CDF	(110 pb^{-1})	PRL 86 (2001) 4472
Polarization J/ψ, $\psi(2S)$	CDF	(110 pb^{-1})	PRL 85 (2000) 2886
"Forward" J/ψ	D0	(10 pb^{-1})	PRL 82 (1999) 35
	CDF	(74 pb^{-1})	PRD 66 (2002) 092001
Diffractive J/ψ	CDF	(80 pb^{-1})	PRL 87 (2001) 251803
Polarization Υ pCu	E866	(2M dimuons)	PRL 86 (2001) 2529

HERA

J/ψ from χ_c (p-C, p-Ti)		HERA-B		PL B561 (2003) 61
Elastic/diffractive	J/ψ γp	H1	(78 pb^{-1})	DESY-03-061
	J/ψ γp	ZEUS	(50 pb^{-1})	EJ C24 (2002) 345
		H1	(20 pb^{-1})	PL B483 (2000) 23
	J/ψ DIS	H1	(27 pb^{-1})	EJ C10 (1999) 373
		ZEUS	(6 pb^{-1})	EJ C6 (1999) 609
	J/ψ large$\|t\|$	ZEUS	(25 pb^{-1})	DESY-02-072 ($\to$ EJC)
	$\psi(2S)$ γp	H1	(77 pb^{-1})	PL B541 (2002) 251
	$\psi(2S)$ DIS	H1	(27 pb^{-1})	EJ C10 (1999) 373
Inelastic	J/ψ γp	H1	(88 pb^{-1})	EJ C25 (2002) 25
	J/ψ DIS	H1	(77 pb^{-1})	EJ C25 (2002) 41
	J/ψ and $\psi(2S)$ γp	ZEUS	(38 pb^{-1})	EJ C27 (2002) 173

Luminosity Delivered and Recorded-CDF



Physics quality data began March 2002
$\sqrt{s}$ = 1.96 TeV

Delivered 225 pb-1
Recorded 180 pb-1 (80%)
83% since February

Summer Conferences
140 pb-1 QCD
110-140 pb-1 EWK
100-110 pb-1 Top+
100-140 pb-1 Exotics
110 pb-1 Bottom

Since Feb 10 2003, silicon in 94% of time

Winter top analyses used 57 pb-1

Direct ψ(2S) Cross Section - CDF

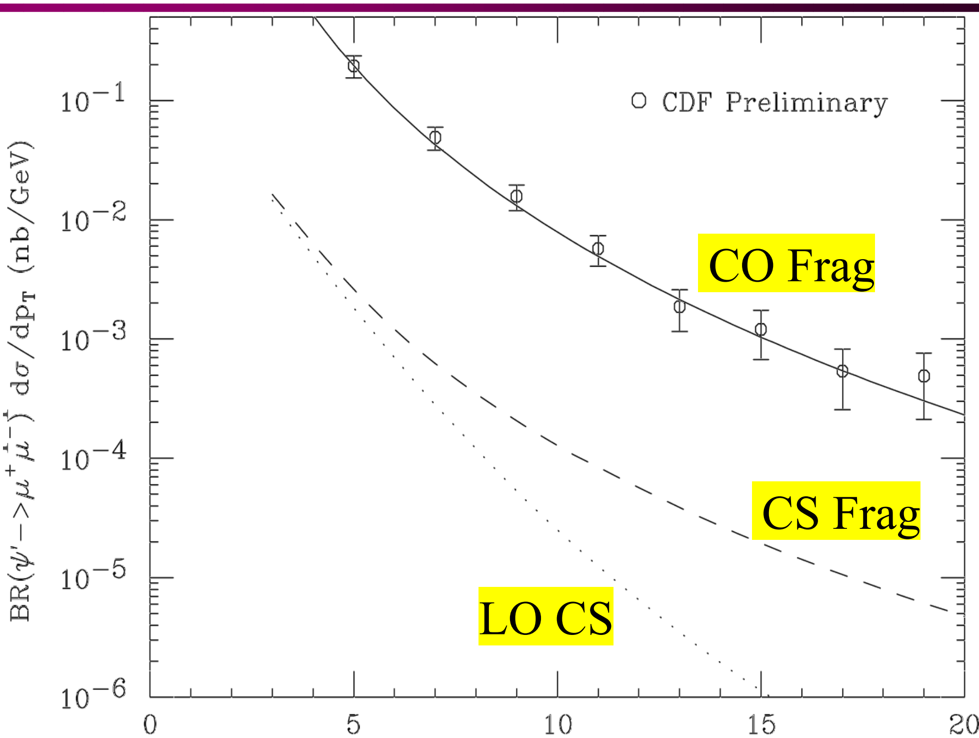
- $\psi(2S) \rightarrow \mu\mu$, Run IA data, 18 pb^{-1}
- "Central muons" ($|\eta| < 0.6$)
- Lifetime information from SVX used to extract prompt component
- *Prompt* $\equiv$ *direct* for ψ(2S)
- Colour singlet fusion: α_S^3/p_T^8
- CS fragmentation (Braaten, Yuan, PRL 71(1993) 1673): α_S^5/p_T^4

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

- 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)



Braaten, Fleming PRL 74(1995) 3327

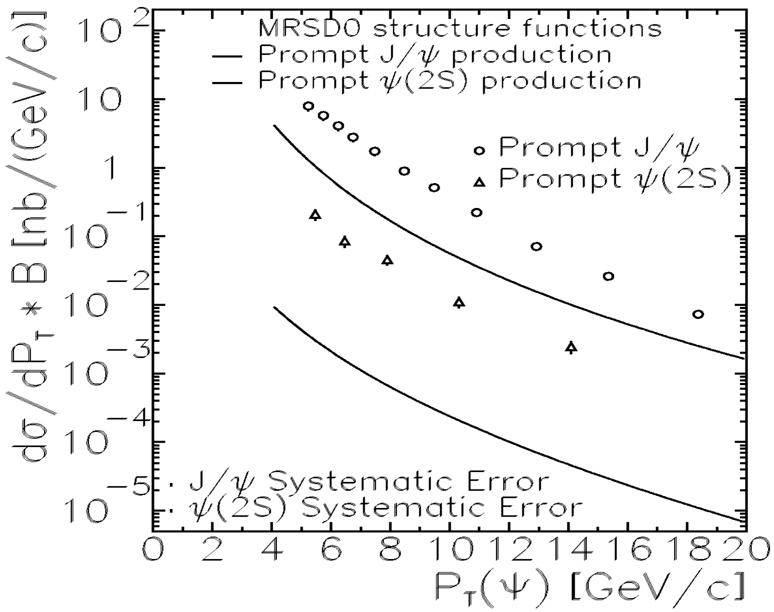
CDF Data: PRL 79(1997) 572

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

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

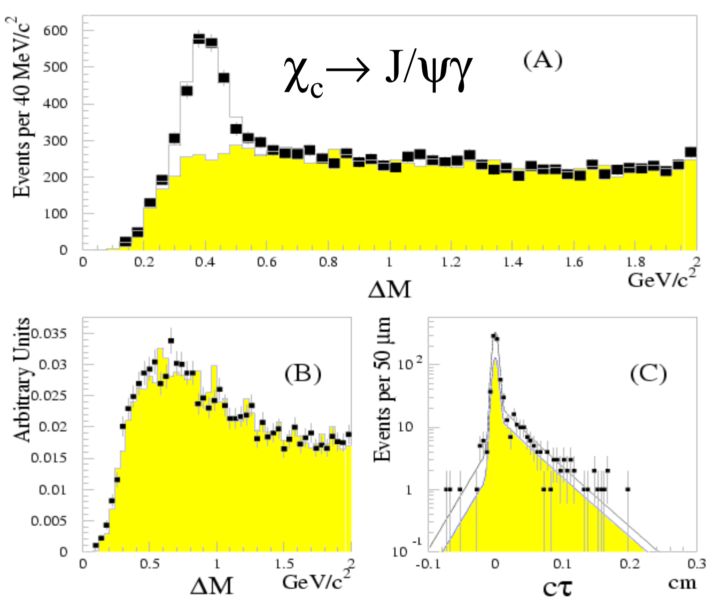
- *Fragmentation dominates at high p_T*

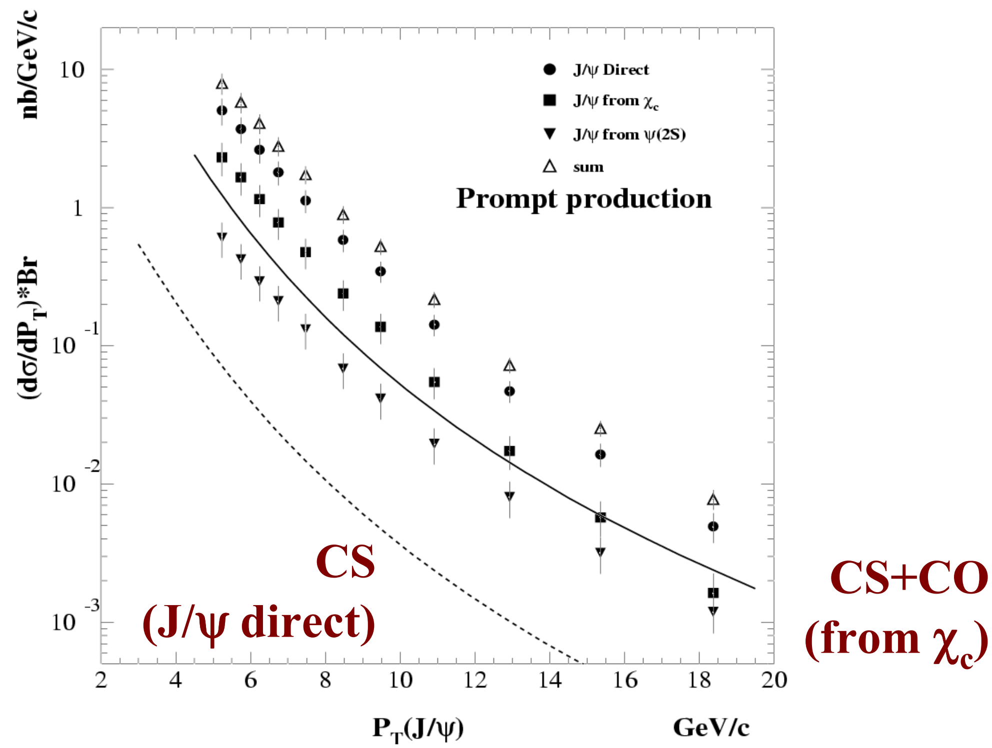
Prompt / Direct J/ψ Cross Section



J/ψ → μμ

- 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

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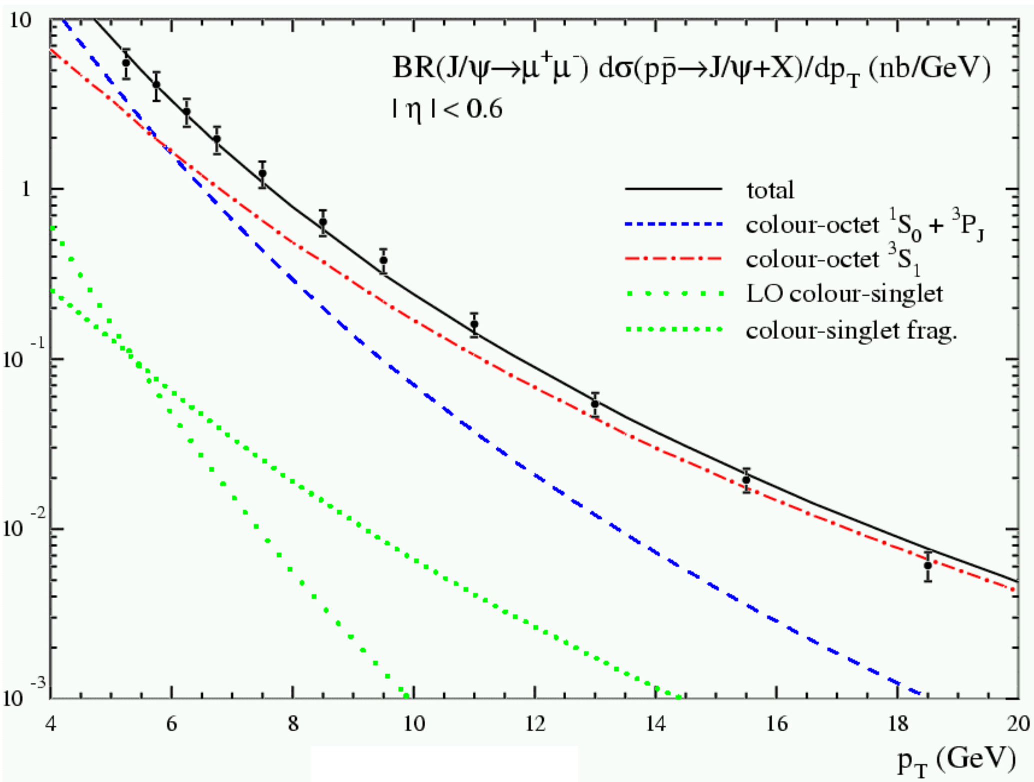
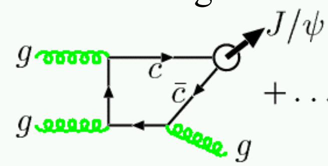
Direct J/ψ Cross Section

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



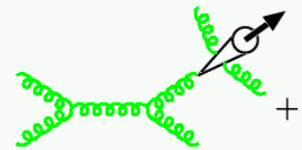
Beneke, Krämer, PRD 55(1997) 5269

LO colour singlet:



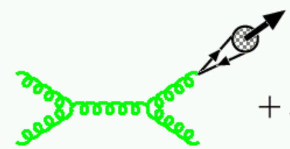
$$+\ldots \qquad \sim \alpha_s^3 \frac{(2m_c)^4}{p_t^8}$$

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



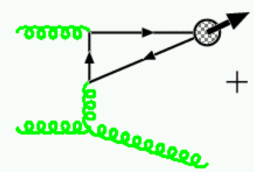
$$+\ldots \qquad \sim \alpha_s^5 \frac{1}{p_t^4}$$

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



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

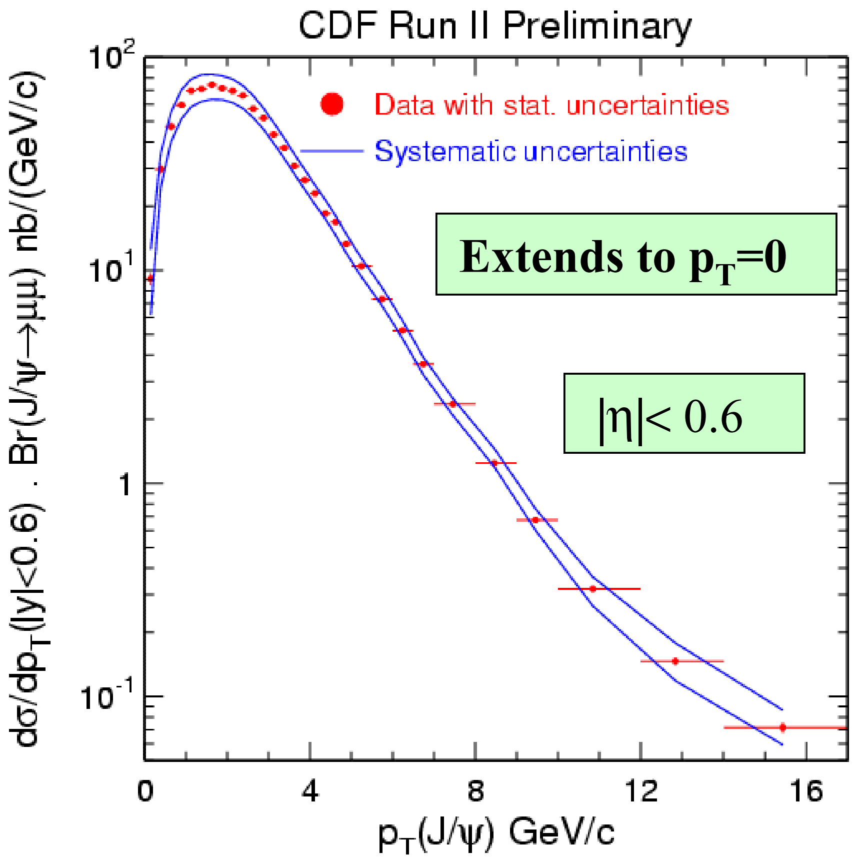
colour-octet fusion: $g + g \to c\bar{c}[^1S_0^{(8)}, {}^3P_J^{(8)}] + g$

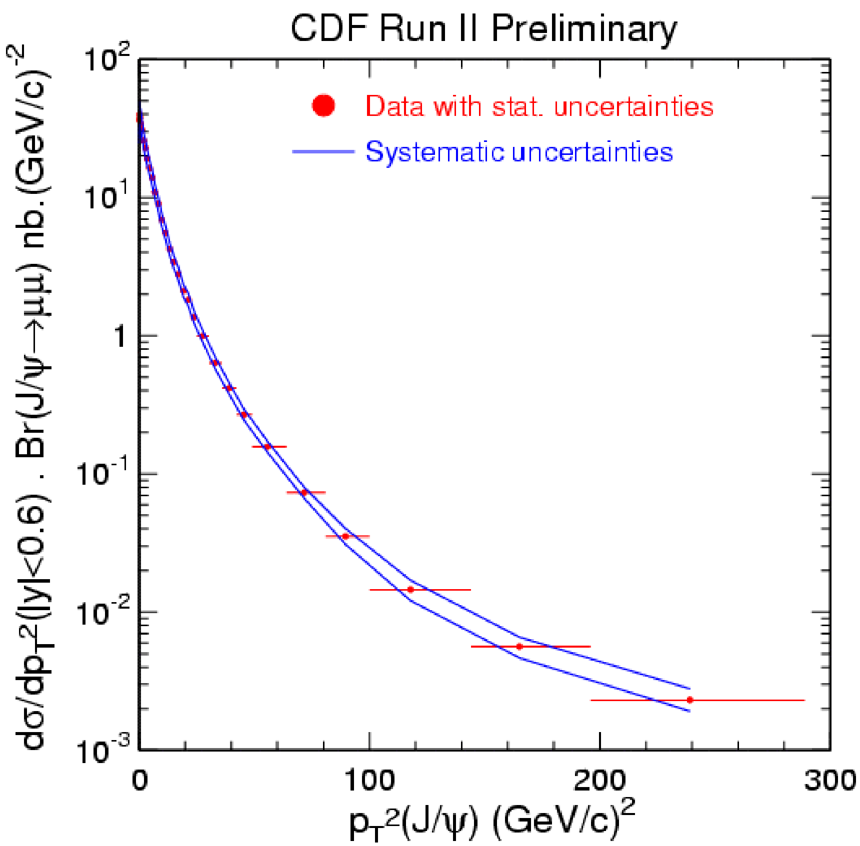


$$+\ldots \qquad \sim \alpha_s^3 \frac{(2m_c)^2}{p_t^6} v^4$$

J/ψ Cross Section – Run II

39.7 pb^{-1}



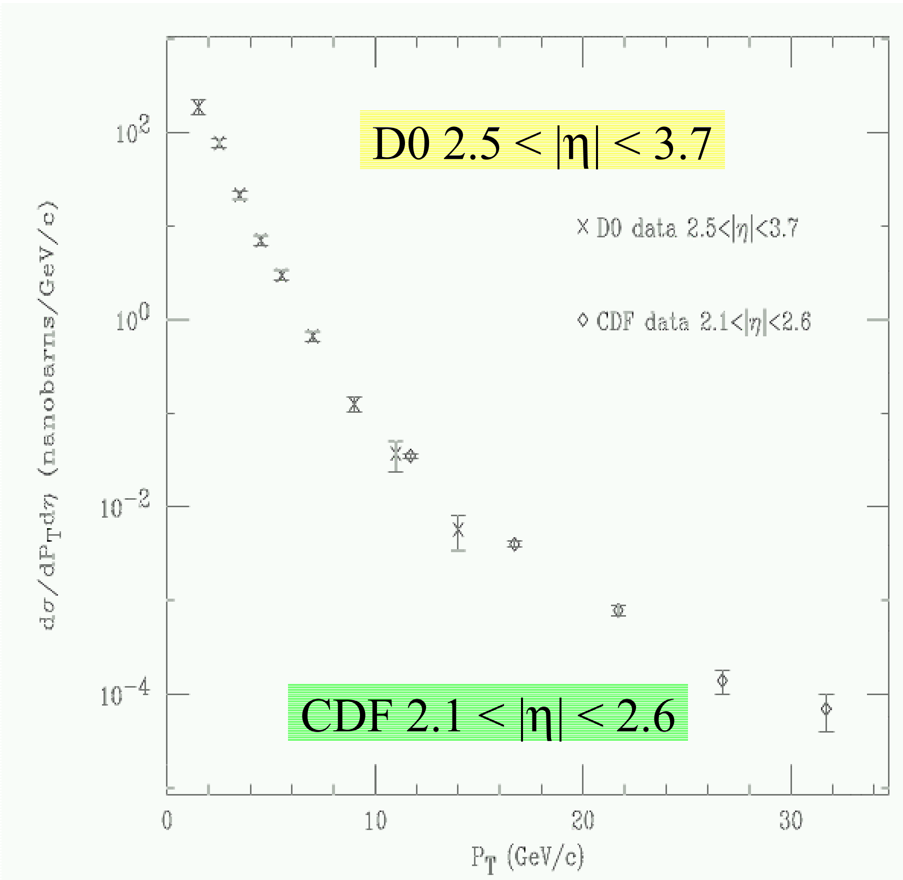


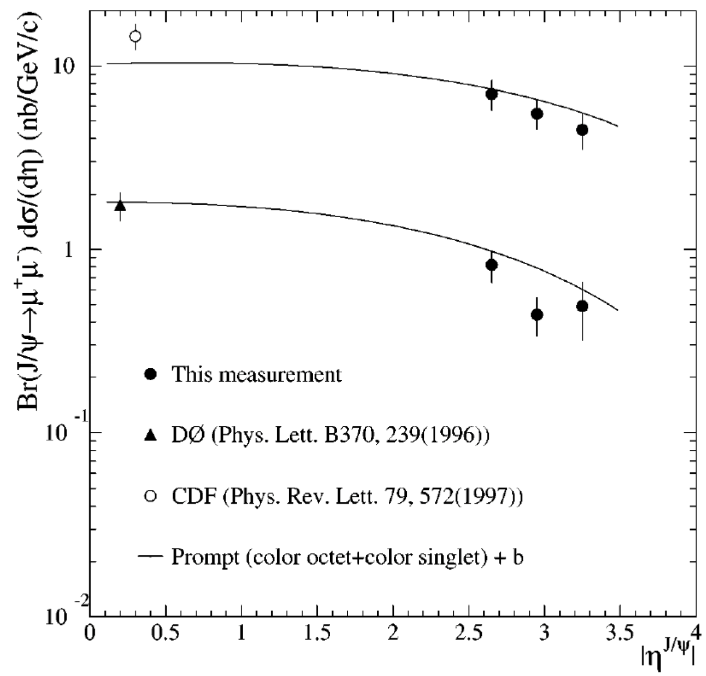
$$\frac{d\sigma_\psi}{dp_T} \bullet BR(J/\psi \to \mu\mu) = \frac{N'(p_T)}{\varepsilon_{rec} \bullet \Delta p_T^{bin} \bullet \int Ldt}$$

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

Forward J/*ψ Production*

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





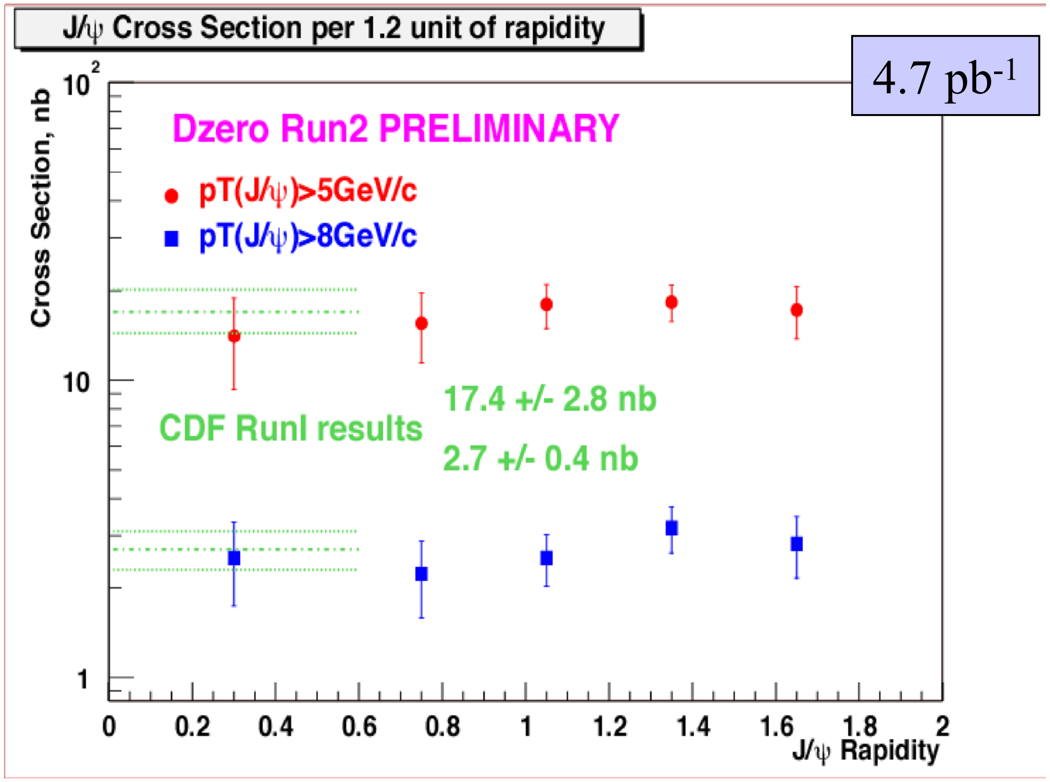
p_T>5GeV

p_T>8GeV

Reasonable agreement between central and forward measurements

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

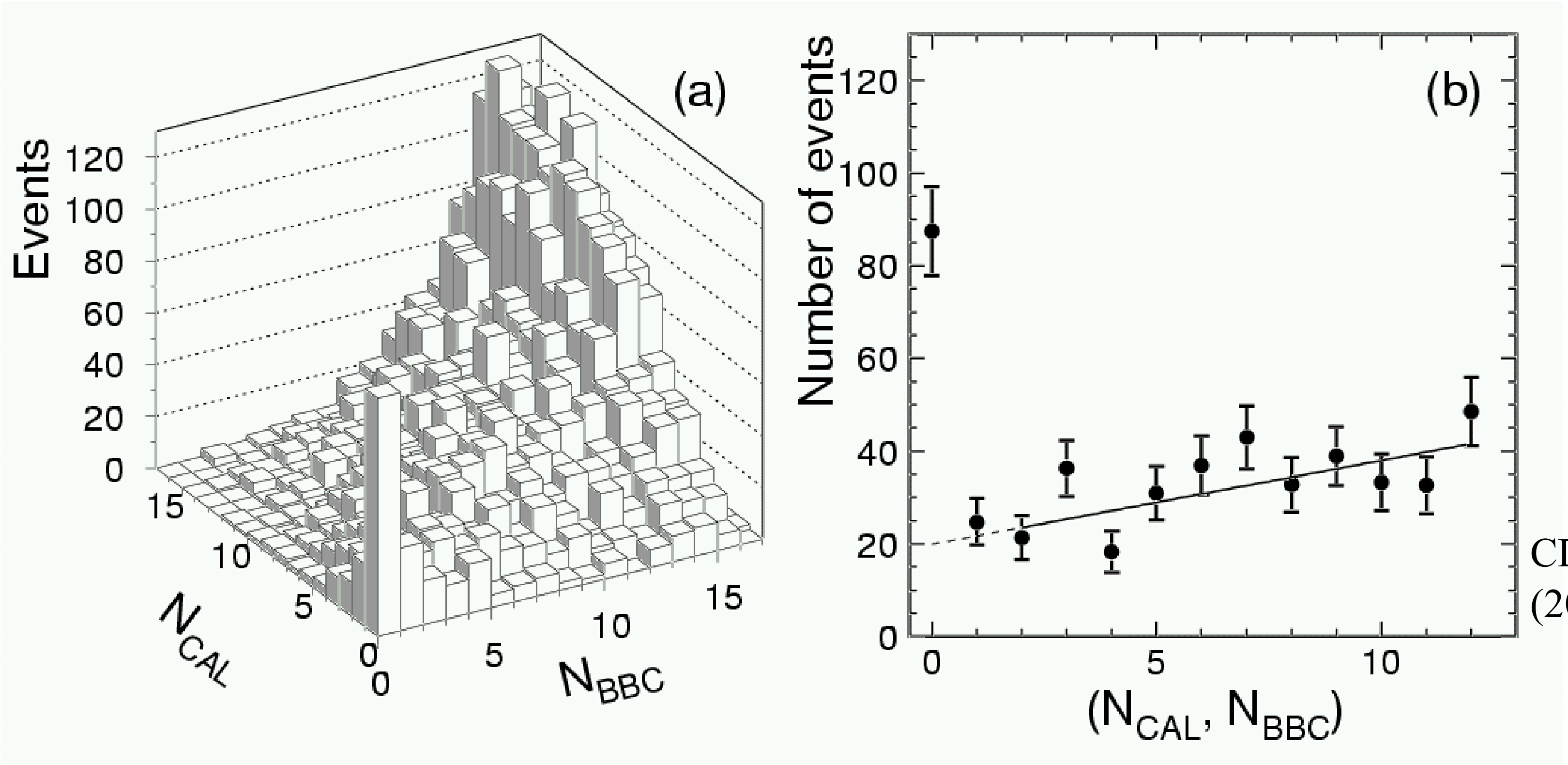
J/ψ Cross Section - Run II



Cross section as a function of rapidity

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: $R_\psi = 1.45 \pm 0.25$ %

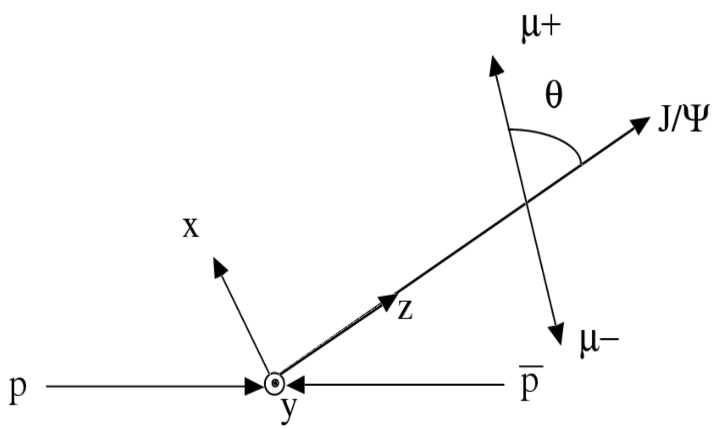
J/ψ Polarization

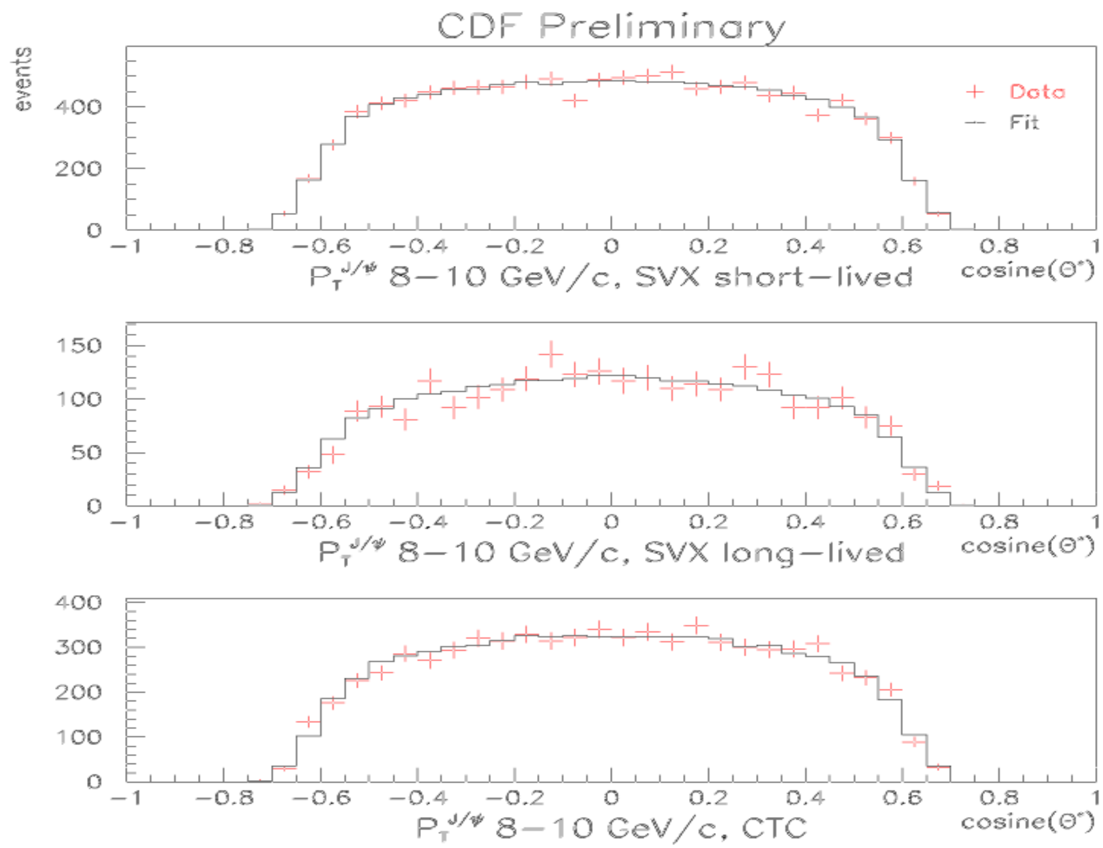
- All CDF Run I data, **$\int$L dt = 110 pb^{-1}**
- $p_T > 4$ GeV, $|y| < 0.6$
- Small acceptance at large $|\cos\theta|$
- χ^2 fit using templates for longitudinal and transverse polarization

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

$$\alpha = 1 \quad \textit{transverse}$$

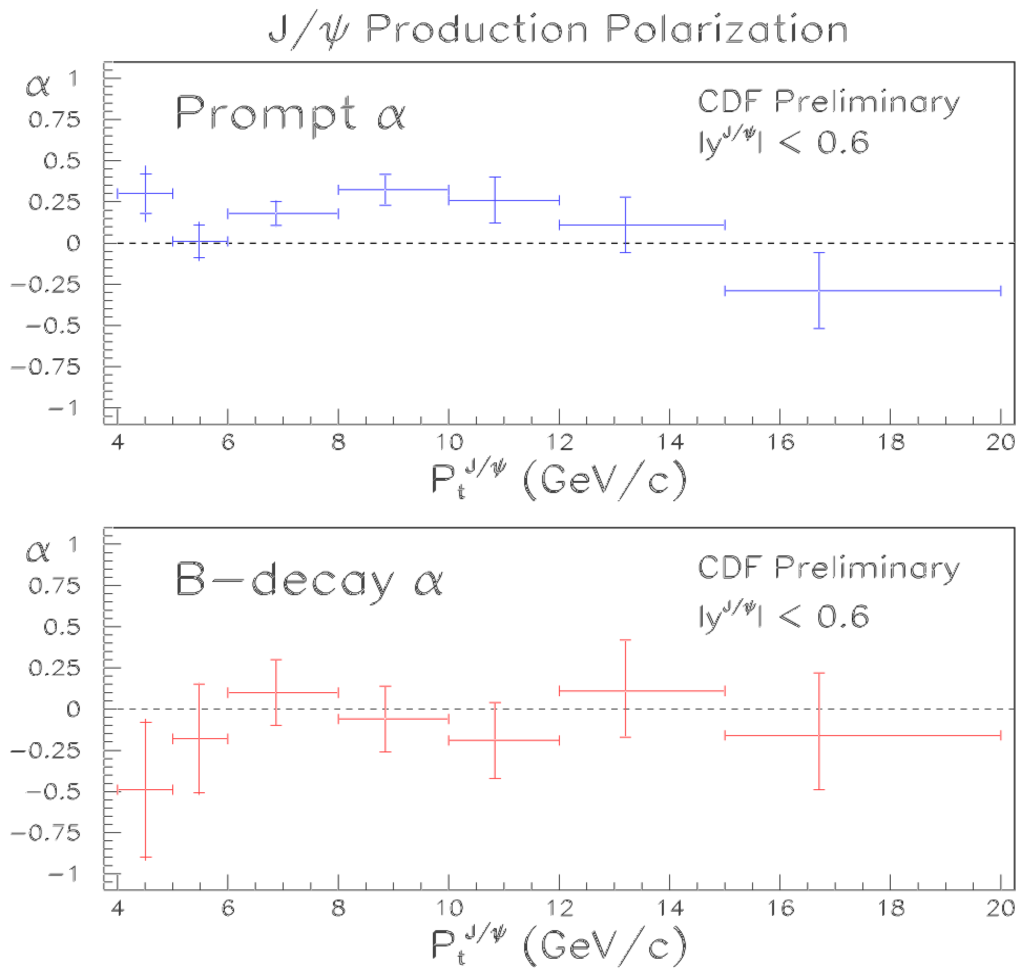
$$\alpha = -1 \quad \textit{longitudinal}$$





CDF, PRL 85 (2000) 2886

J/ψ Polarization

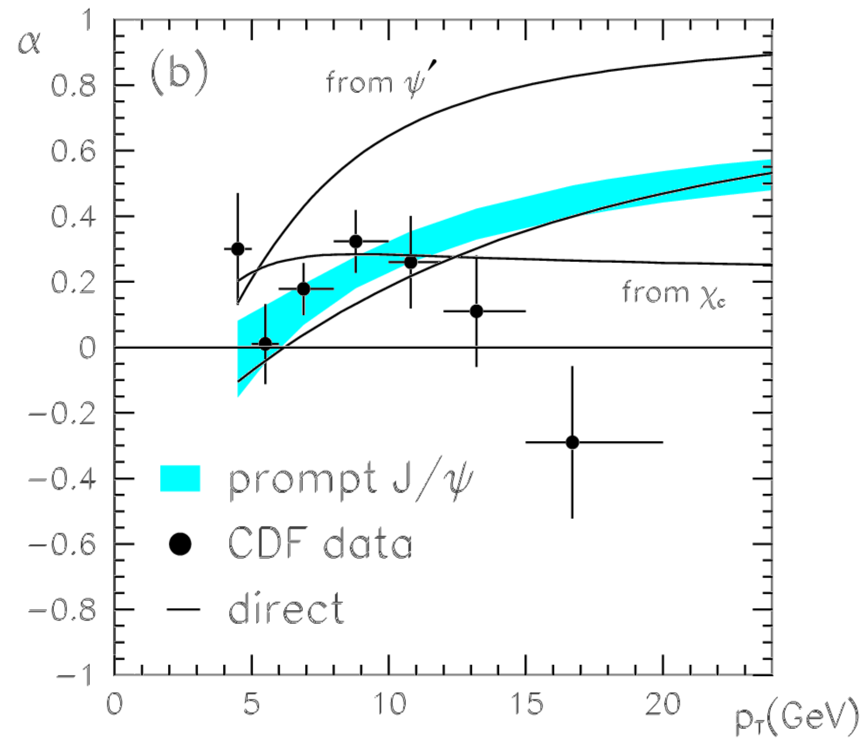


J/ψ from B decays
essentially unpolarized

CDF, PRL 85 (2000) 2886

Prompt J/ψ Polarization

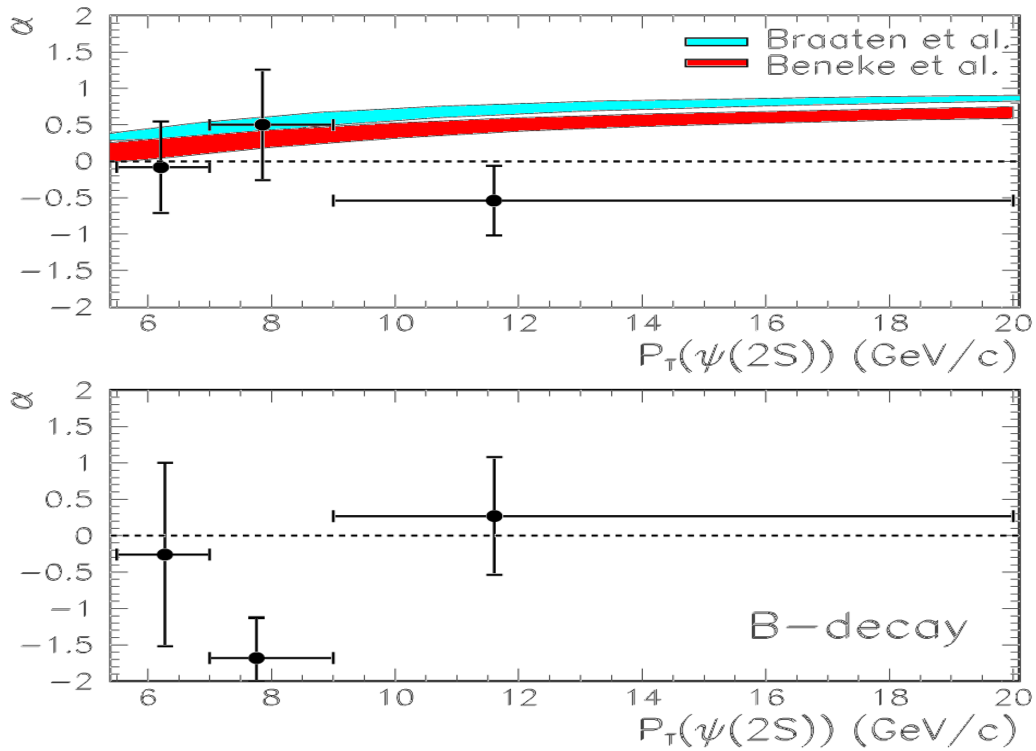
- Need to take into account ψ(2S) and χ_c contributions
- Data do not show a trend towards transverse polarization at large p_T
- Phenomenological models give better description
  - E.g. **colour evaporation model:** mostly unpolarized J/ψ at large p_T



Braaten, Kniehl, Lee
PRD 62 (2000) 094005

ψ(2S) Polarization

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

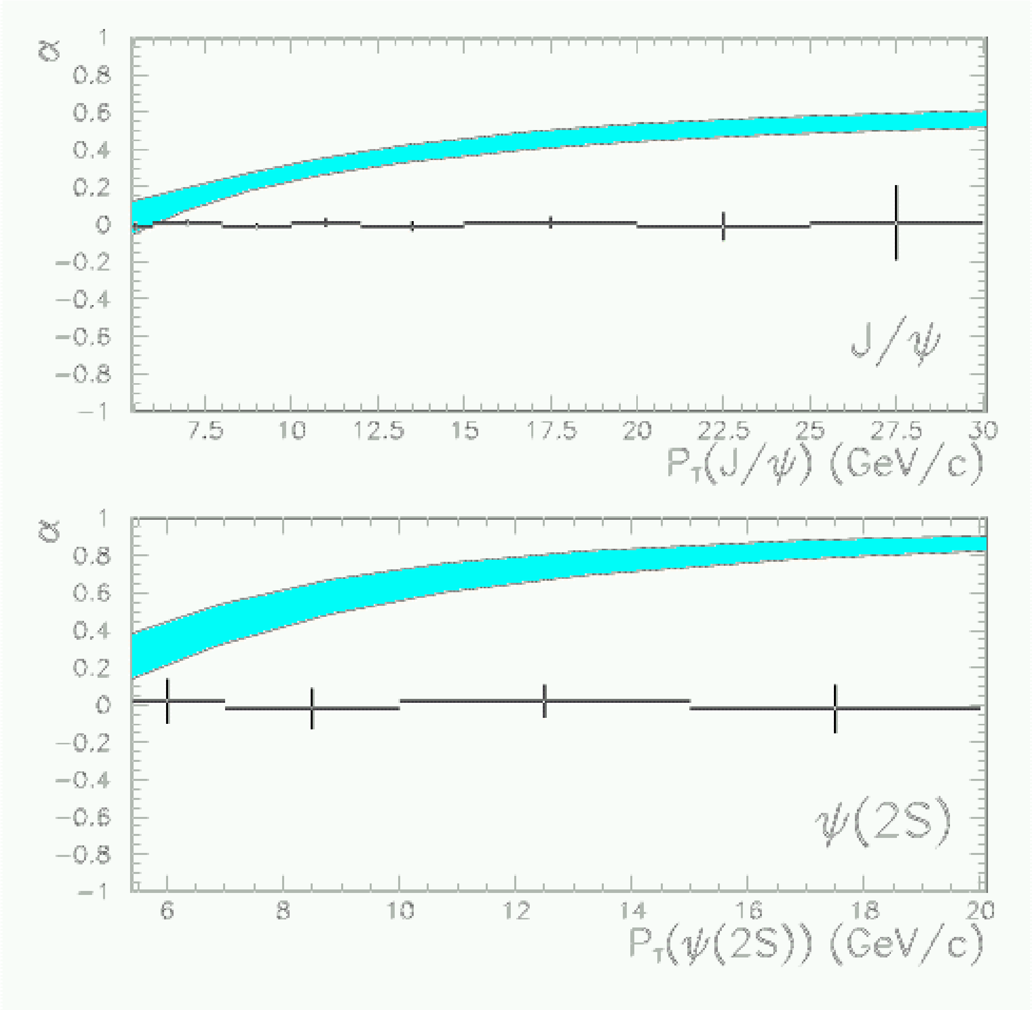


CDF, PRL 85 (2000) 2886

Polarization in Run II

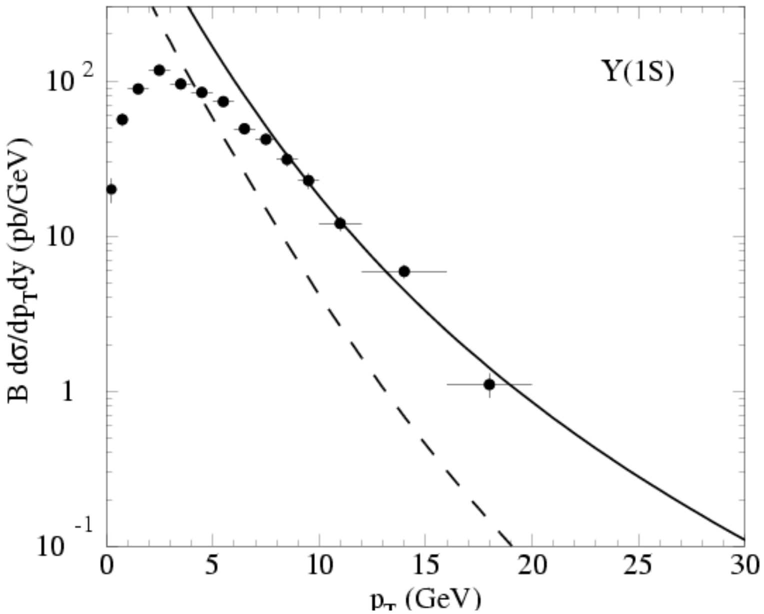
CDF study:

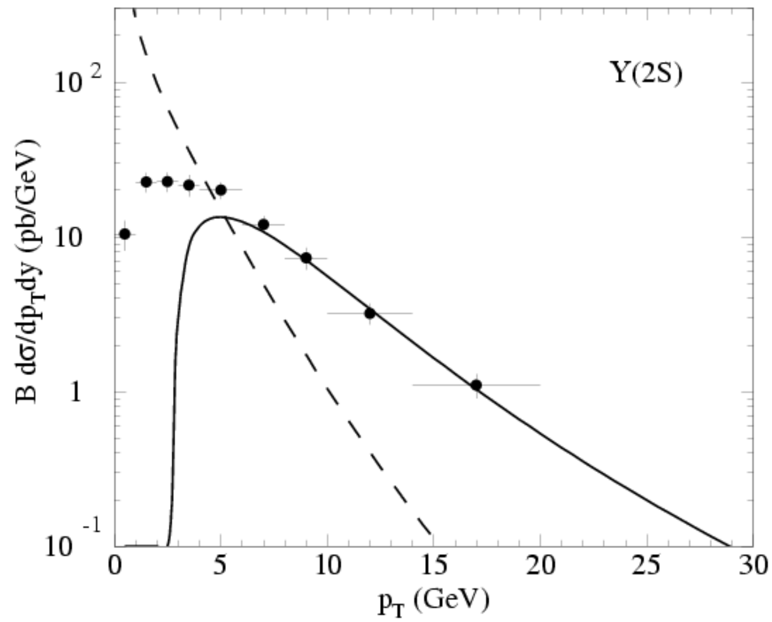
- Assume factor 50 in effective statistics
  - Integrated luminosity 2 fb^{-1}
  - Better SVX coverage (separate prompt/B)
- Lower dimuon trigger threshold (1.5GeV)
  - Able to measure down to $p_T(J/\psi)$ of ≈ 0
- Systematic uncertainties still small at larger p_T

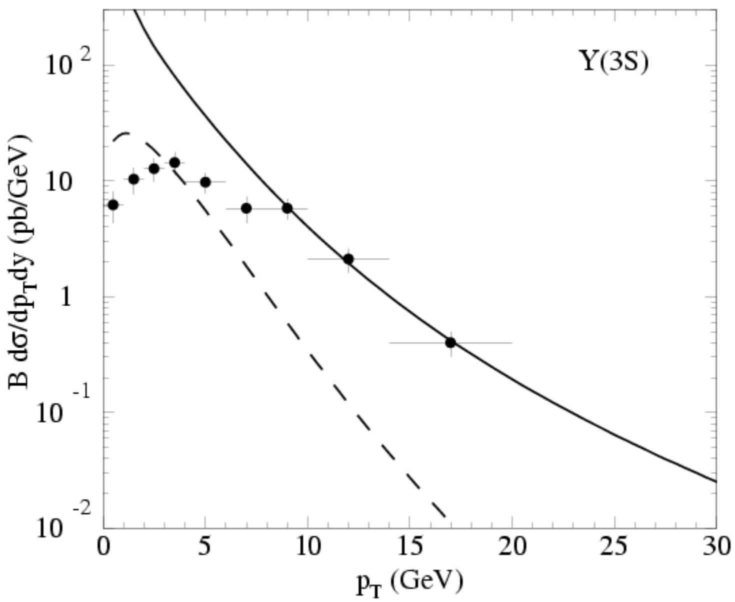


ϒ Cross Section at CDF

Run I:
PRL 88 (2002)161802



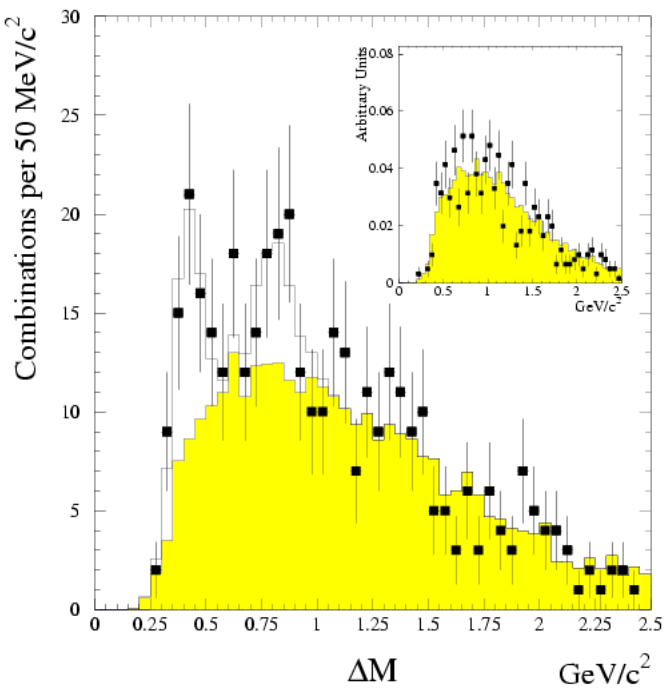




- smaller discrepancy with CSM but similar to $c\bar{c}$ result
- NRQCD CS+CO terms able to fit data with $p_T > 8$ GeV/c

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

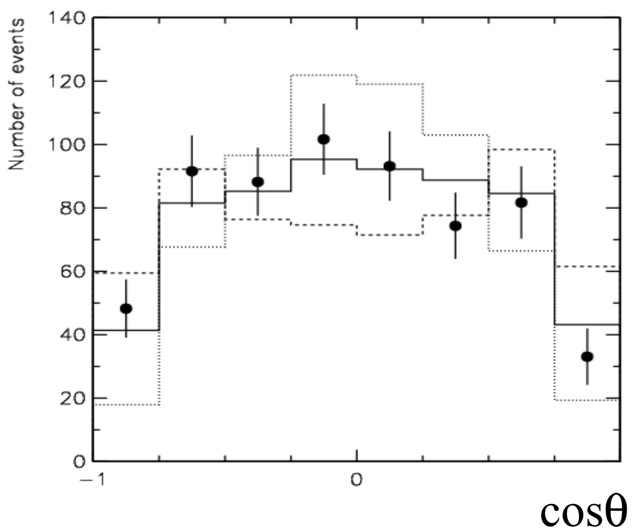
From $\Upsilon(2S)$: $(10.7^{+7.7}_{-4.8})\%$

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

Input in theoretical calculations of Bottomonium cross sections

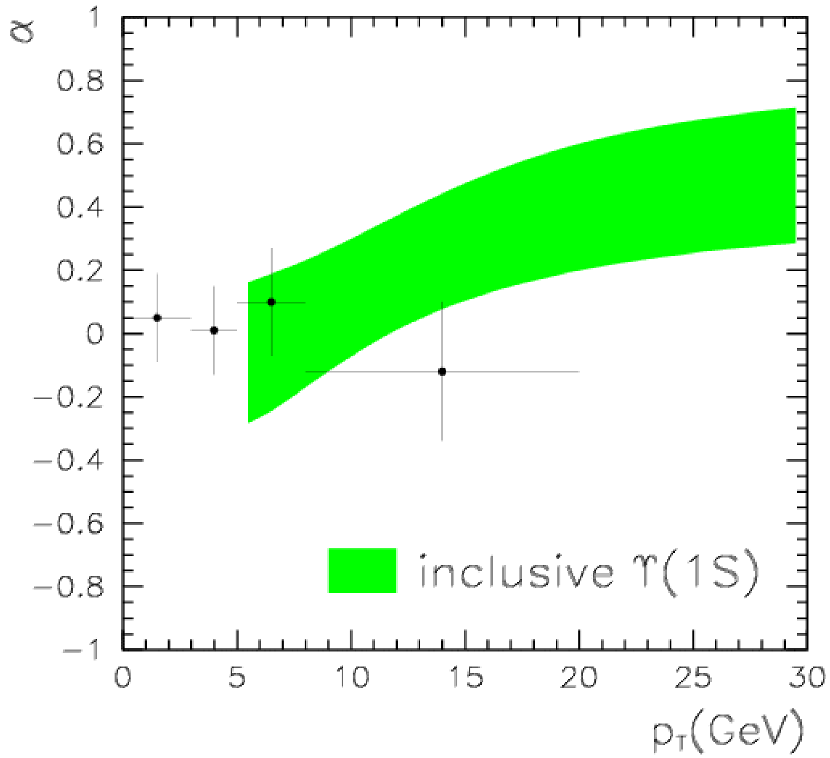
ϒ Polarization at CDF

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

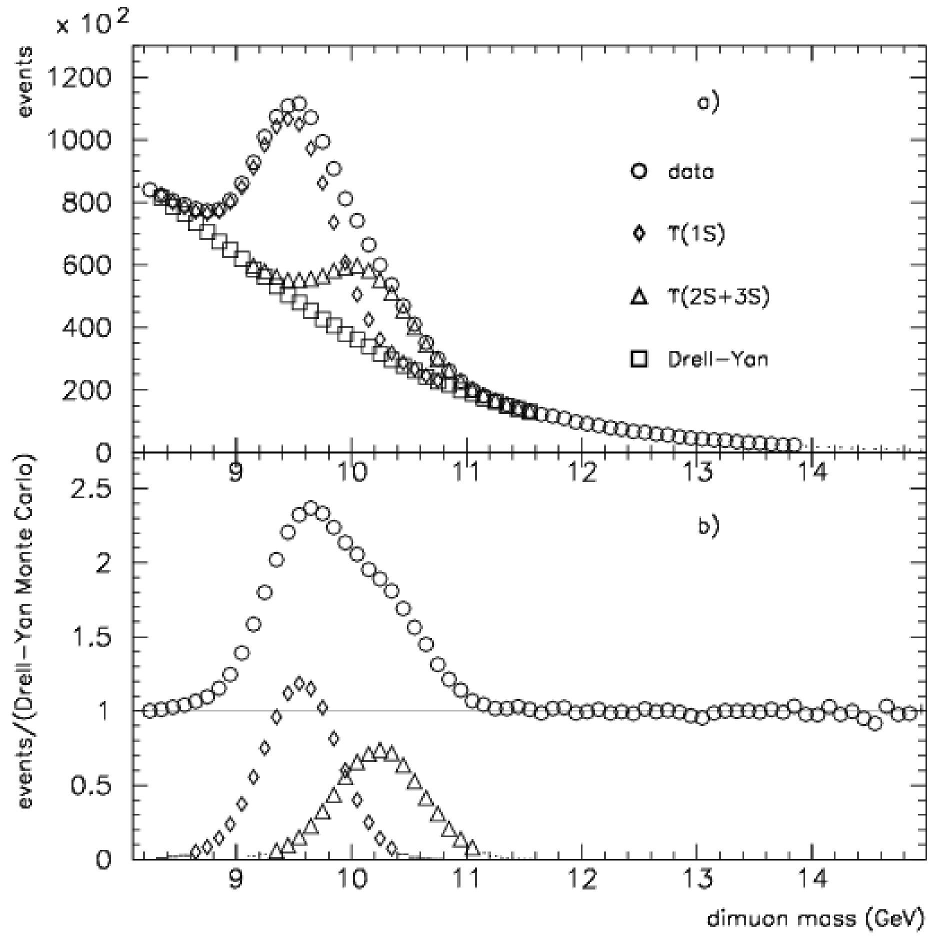
E866/Nusea, $\sqrt{s}$=38.8 GeV

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

$0 < x_F < 0.6$

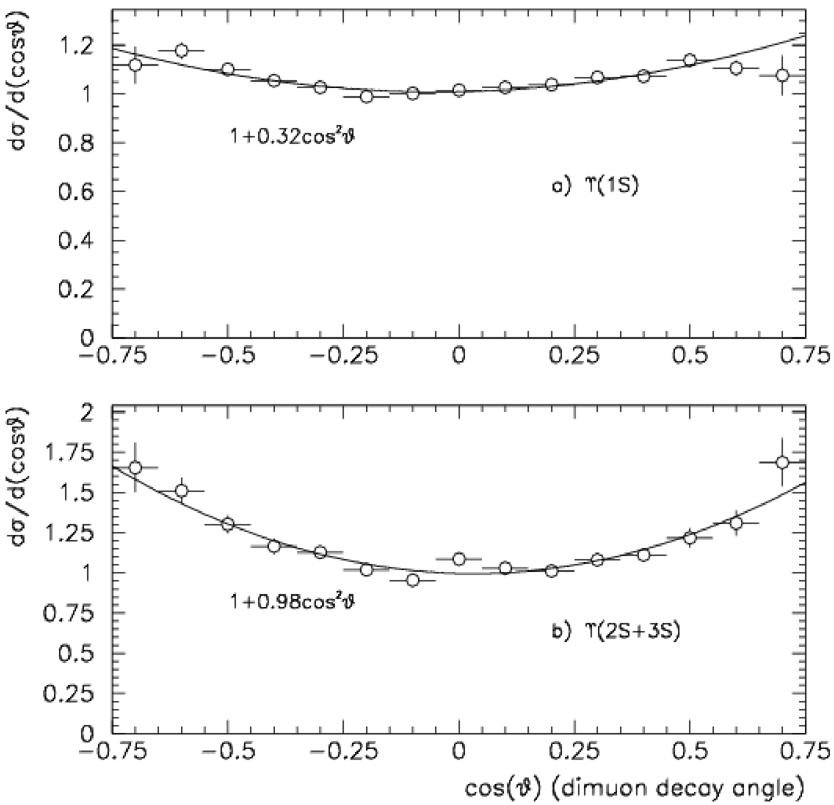
$p_T < 4$ GeV/c
(transverse to beam axis)

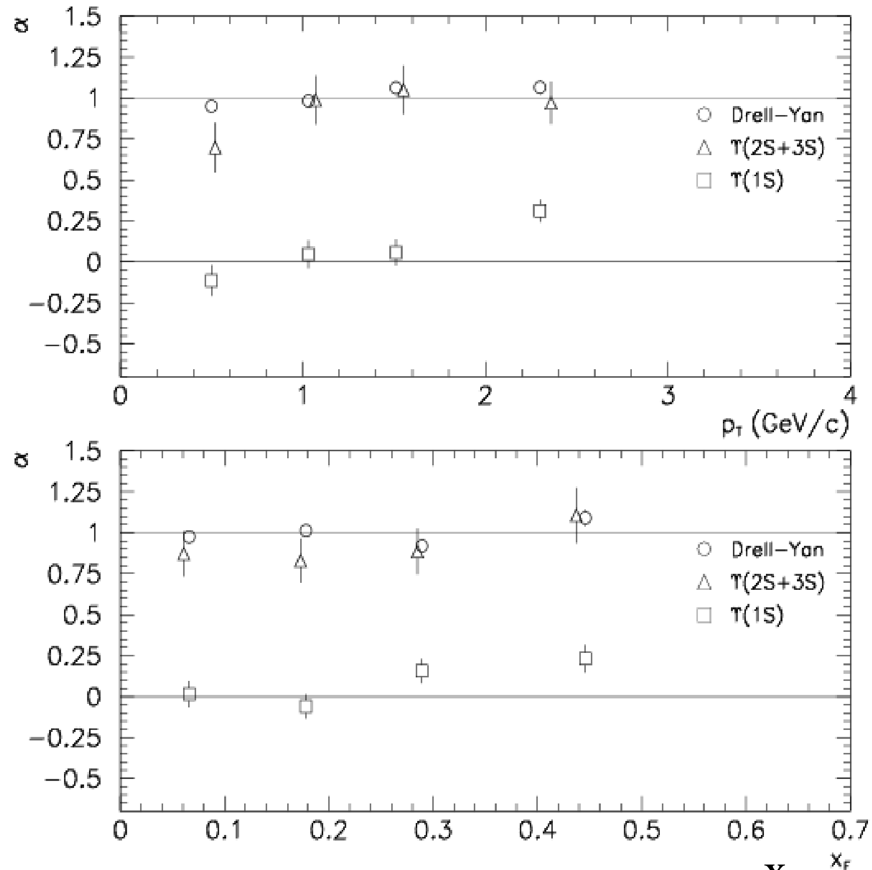
- Υ(2S) and Υ(3S) not distinguished
- Subtract Drell-Yan μμ continuum
(100% transverse polarization)
- sideband fit: α=1.008 ± 0.016 ± 0.020



E866/Nusea, ϒ polarization

cosθ distributions for $p_T > 1.8$ GeV/c





x_F

- inclusive ϒ(1S):

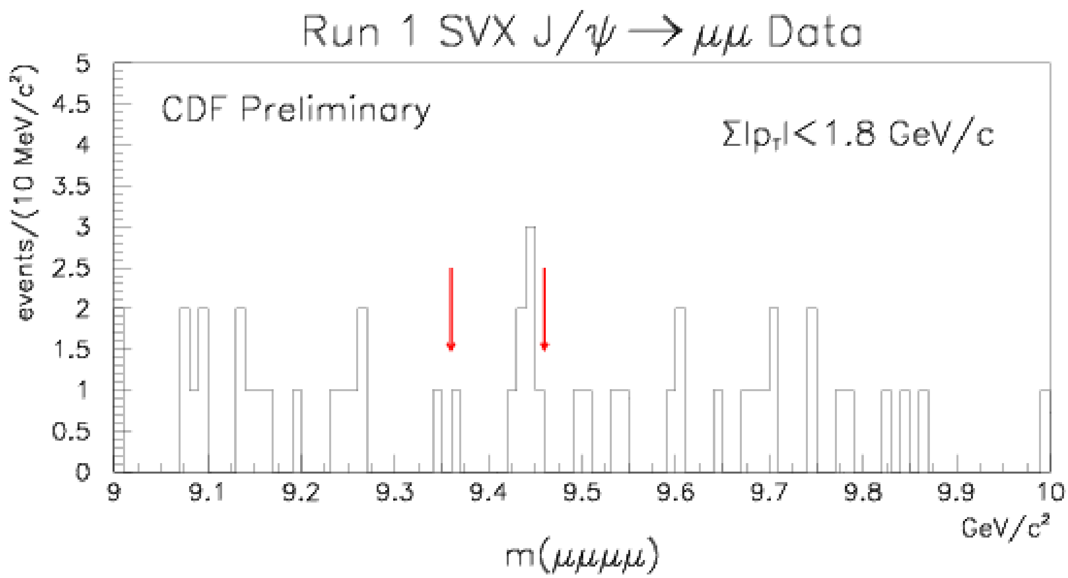
NRQCD: α= 0.28 to 0.31, avg over p_T, x_F
Observed: α= 0.07± 0.04(stat)± 0.06(sys)

- inclusive ϒ(2S) + ϒ(3S):

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

Search for η_b at CDF

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



Braaten, Fleming, Leibovich
PRD 63 (2001) 094006

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

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)

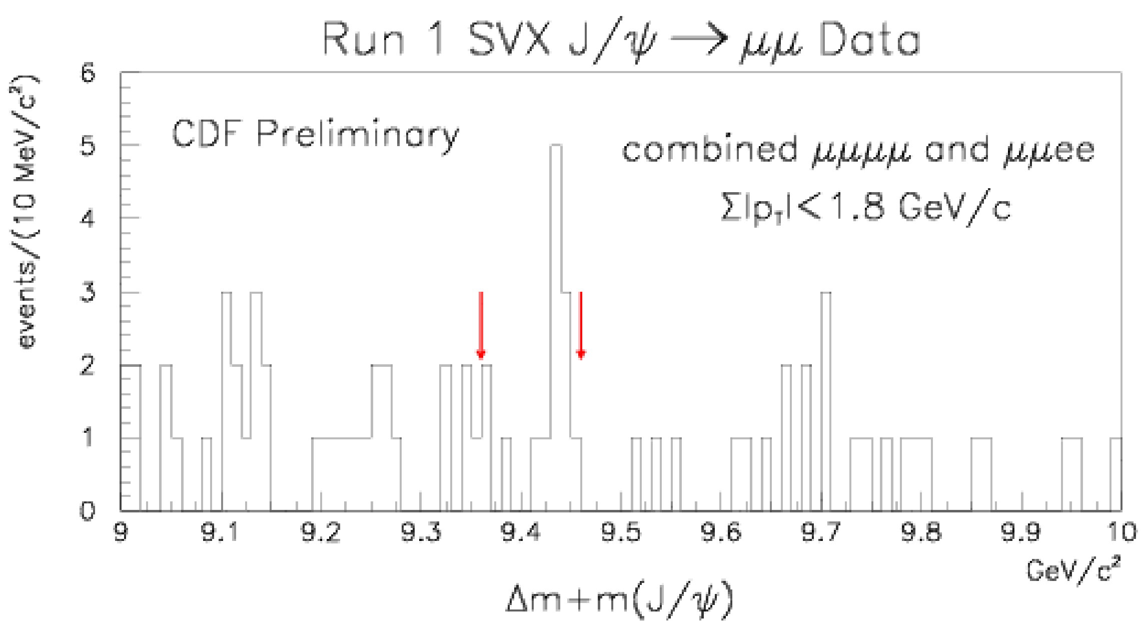
Search for η_b at CDF

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

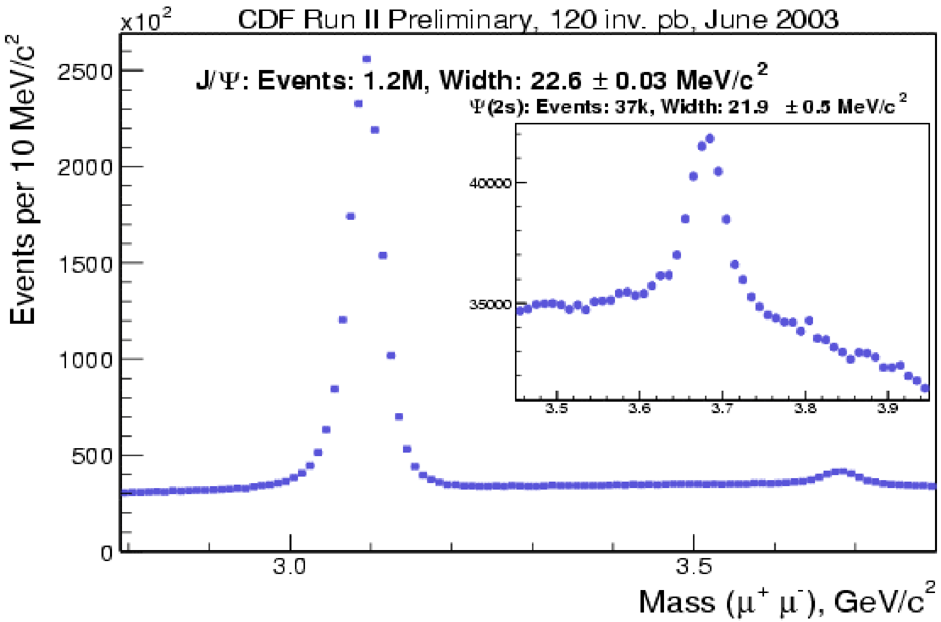


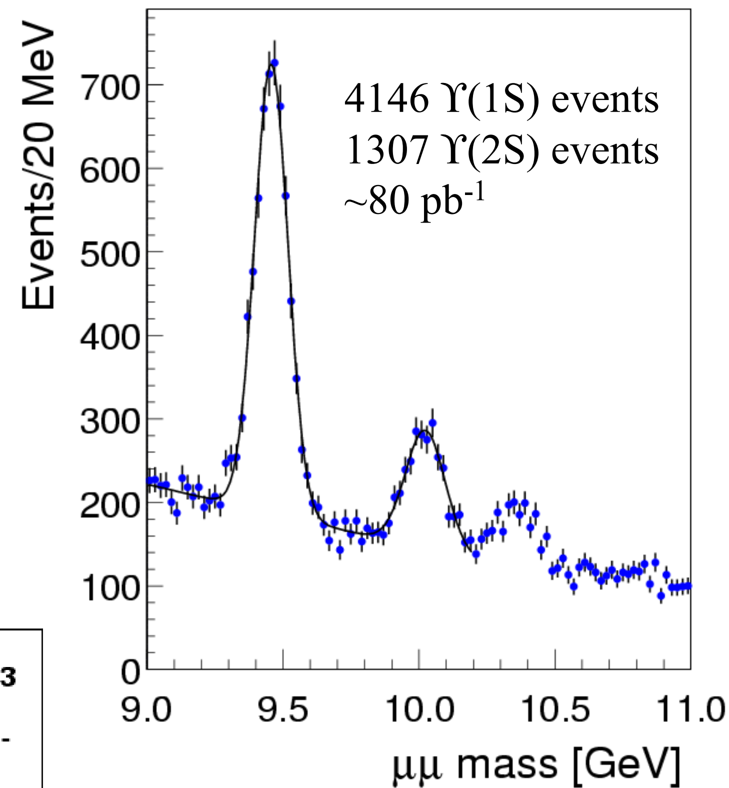
Improves apparent significance
Supportive of signal hypothesis
Need more data for confirmation

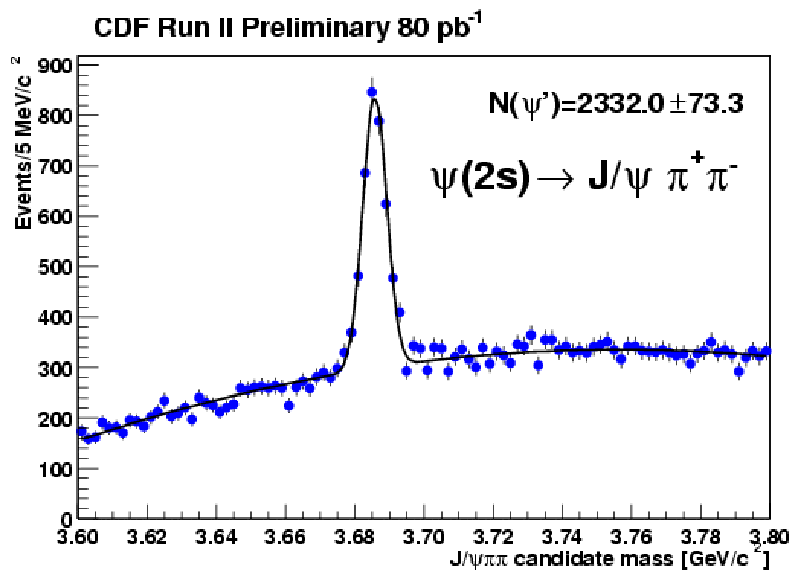
Prospects for Run II

- $\int$**L dt** $\approx$ **1.4** fb^{-1} by end of FY05, $\int$**L dt** $\approx$ **9** fb^{-1} by end of FY09
  - Run II is well underway, data samples about 30% bigger than Run I now
- Will get many J/ψ's and ψ(2S) for free, but
  - Is the charm system massive enough?
  - For J/ψ, will always have feed-down to J/ψ final states
- For most measurements, there are now two experiments
- Also better muon and silicon coverage, improved trigger capabilities, decays into e^+e^- (?)
- There will be other possible measurements that can shed light on the colour octet issue
  - h_c, χ_c, Υ, χ_b... production cross sections
  - Associated jets in direct production

Run II - CDF





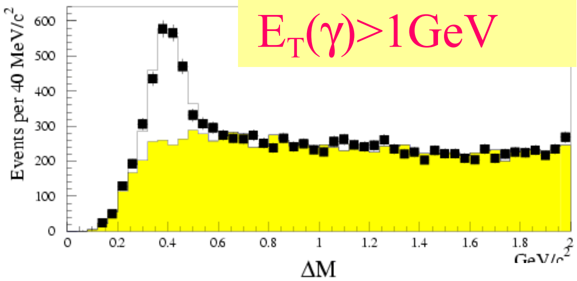


All four tracks in silicon

$3.5\ MeV/c^2$ resolution →

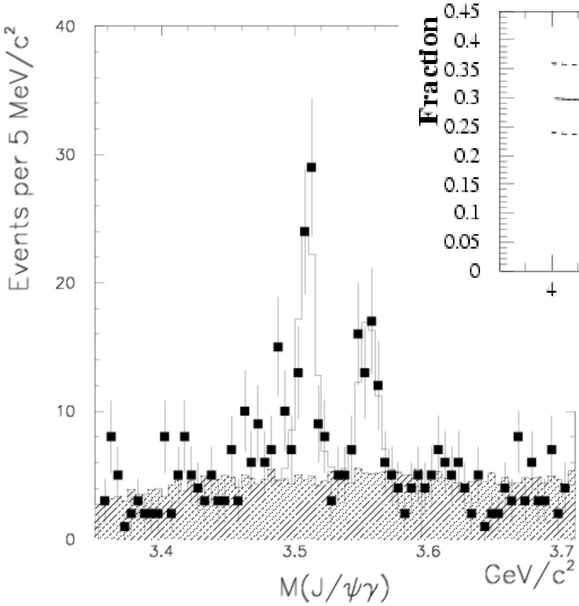
Run II – (CDF/D0 on χ_c)

γ in calorimeter
$E_T(\gamma)$>1GeV

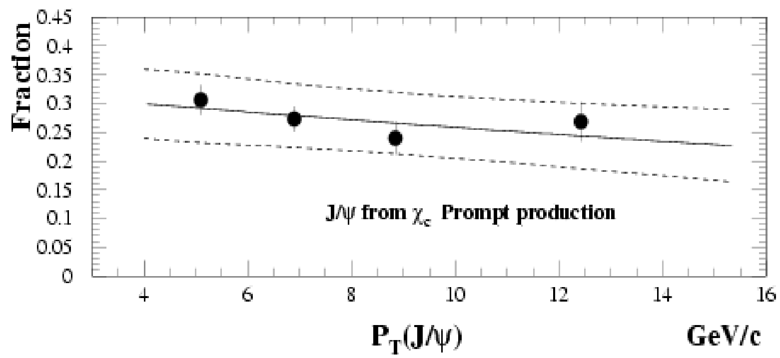


CDF - Run I

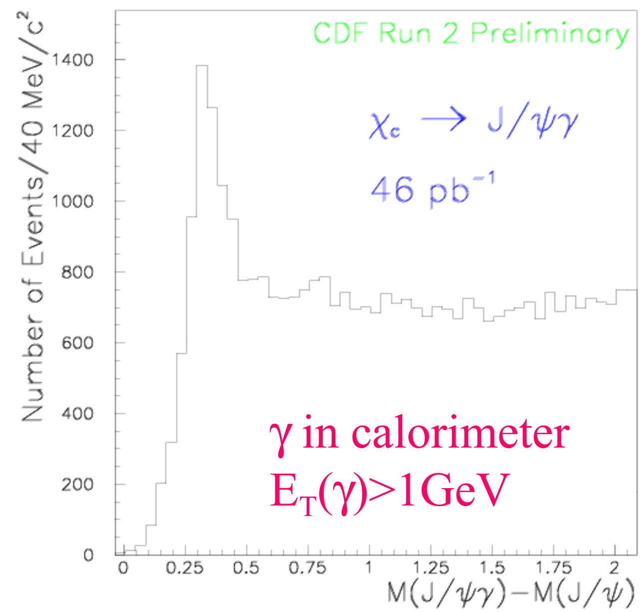
PRL 79 (1997) 578
PRL 86 (2001) 4472



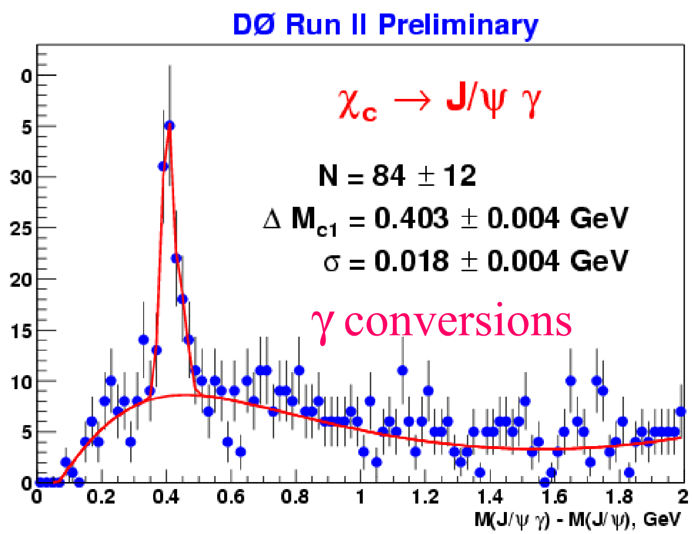
γ conversions



CDF Run II



γ in calorimeter
$E_T(\gamma)$>1GeV



γ conversions

Tevatron/Fixed Target Summary

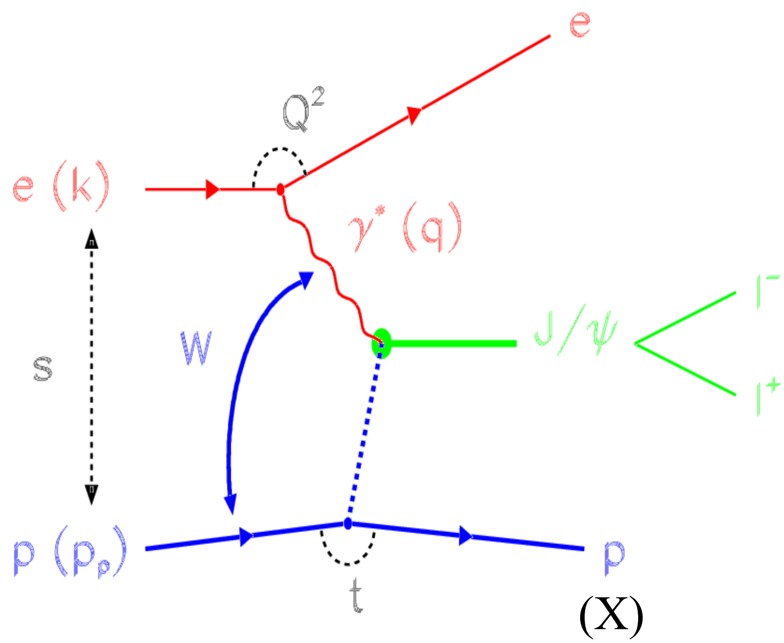
- ***Tevatron:***
  - Direct J/ψ and ψ(2S) production (CDF) is in excess of CSM predictions by a factor of ~50
  - J/ψ cross section in the $(2.5 < |\eta^{J/\psi}| < 3.7)$ range (D0) consistent with CDF data for central J/ψ production
  - J/ψ and ψ(2S) polarization measurements (CDF) appear not to support the COM prediction (more statistics needed)
  - $\sigma\chi_{c2}/\sigma\chi_{c1} = 0.96 \pm 0.27(stat) \pm 0.11(sys)$ (CDF)
  - 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:
  - Υ(1S): significant positive transverse production polarization for either $p_T > 1.8$ GeV/c or $x_F > 0.35$ (E866)
  - Υ(2S+3S) (unresolved): large transverse production polarization at all measured p_T and x_F (E866)

Quarkonia at HERA



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

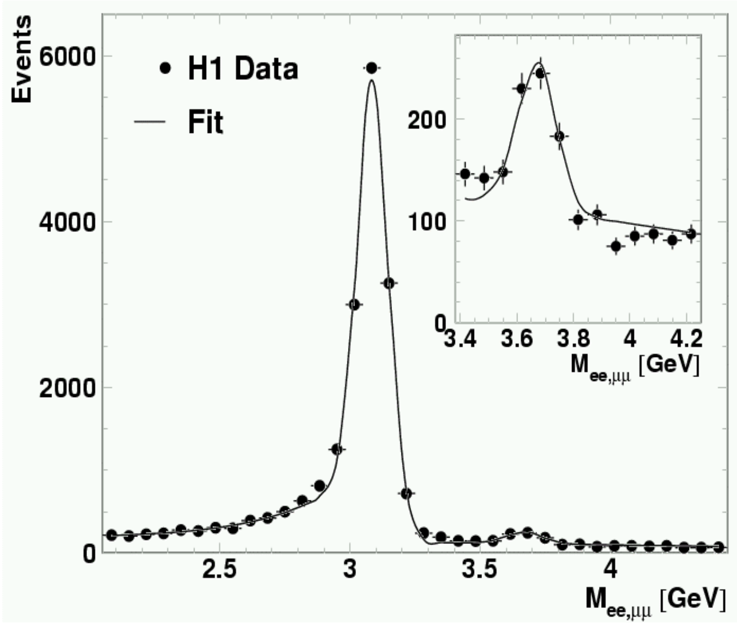
$$W^2 := (p_p + q)^2 \approx Q^2 / x$$

$$Q^2 :\approx xys$$

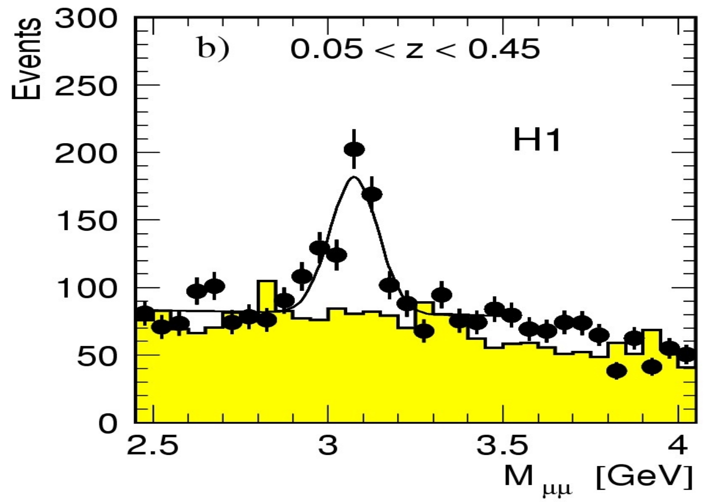
- DIS
  - $1 < Q^2 < 100$ GeV^2
- Tagged/untagged photoproduction
  - Scattered e not seen in main detector
  - Median $Q^2 \cong 10^{-4}$ GeV^2
- Decays into e^+e^- and $\mu^+\mu^-$
- Central tracking ($|\eta| < 1.8$)
  - $30 < W < 180$ GeV
  - In addition, dedicated analyses with specific statistical and systematic limitations (forward muon spectrometer, backward calorimetry, ...)

J/ψ at HERA

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

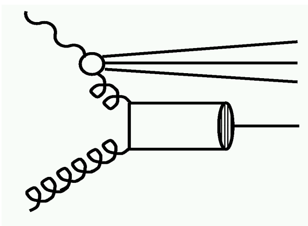


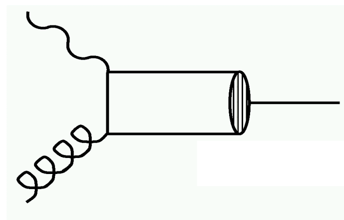
- Order of magnitude comparable
  - "Elastic" $z \approx 1 \; (M_X = m_p)$
  - p diffractive dissociation $z \approx 1 \; (\sigma \propto 1/M_X^2)$
  - "Inelastic" $z < 1$
- At small z contributions from
  - Resolved photon
  - B production
- Background increases with decreasing z



HERA Production Mechanisms

Inelastic





"resolved" (gg-fusion) (z<0.3)

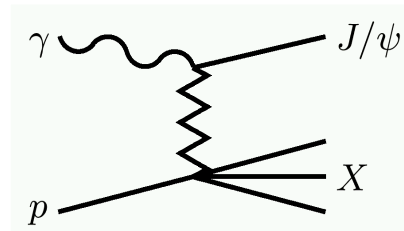
direct (γg-fusion) (z>0.3)

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

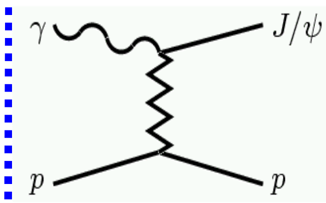
J/ψ from χ_c decays (not subtracted)
(1% of inelastic, up to 7% at lowest z)

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

p-dissociation



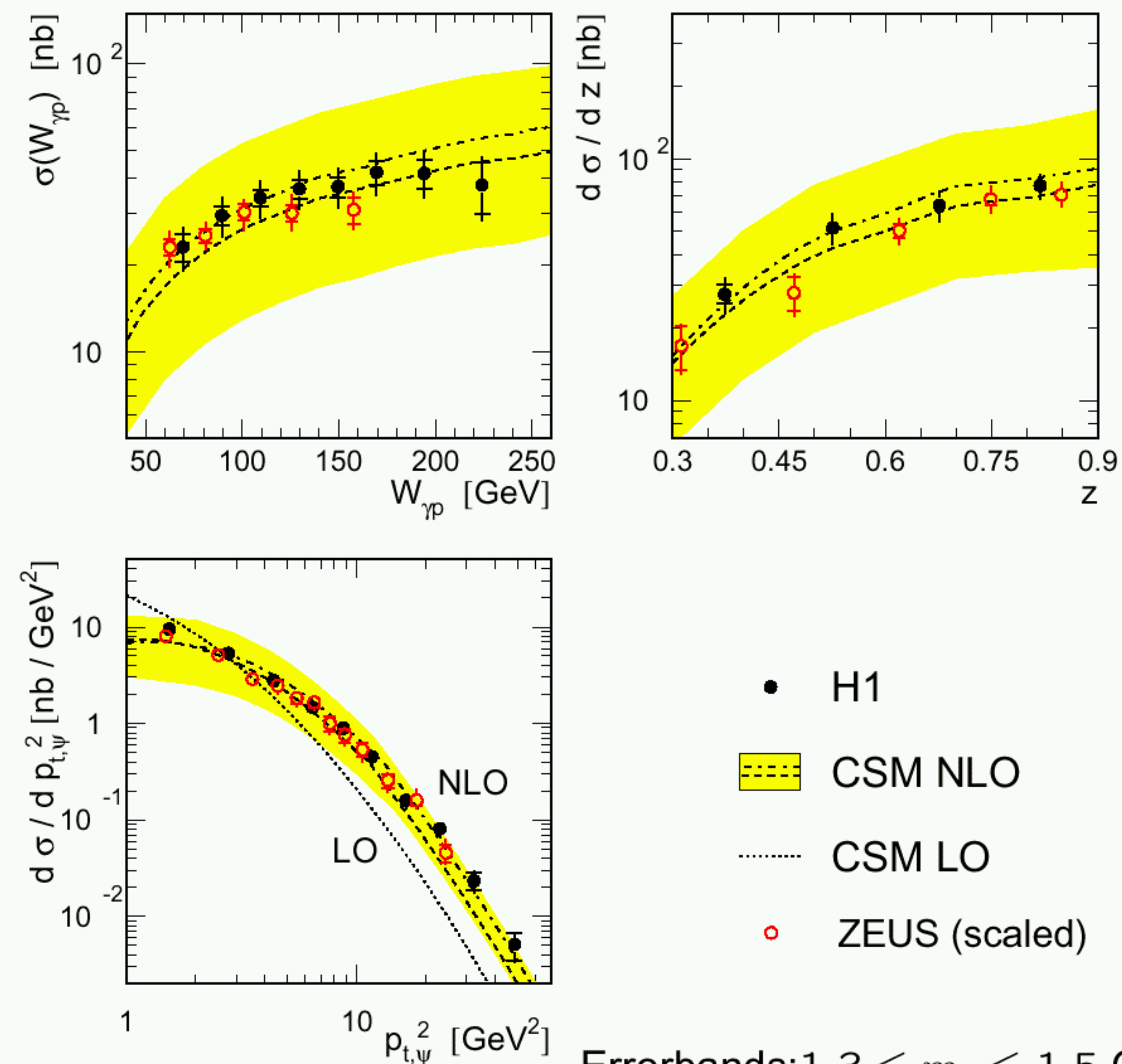
Elastic



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

"Forward tagging"

J/ψ Photoproduction: CSM



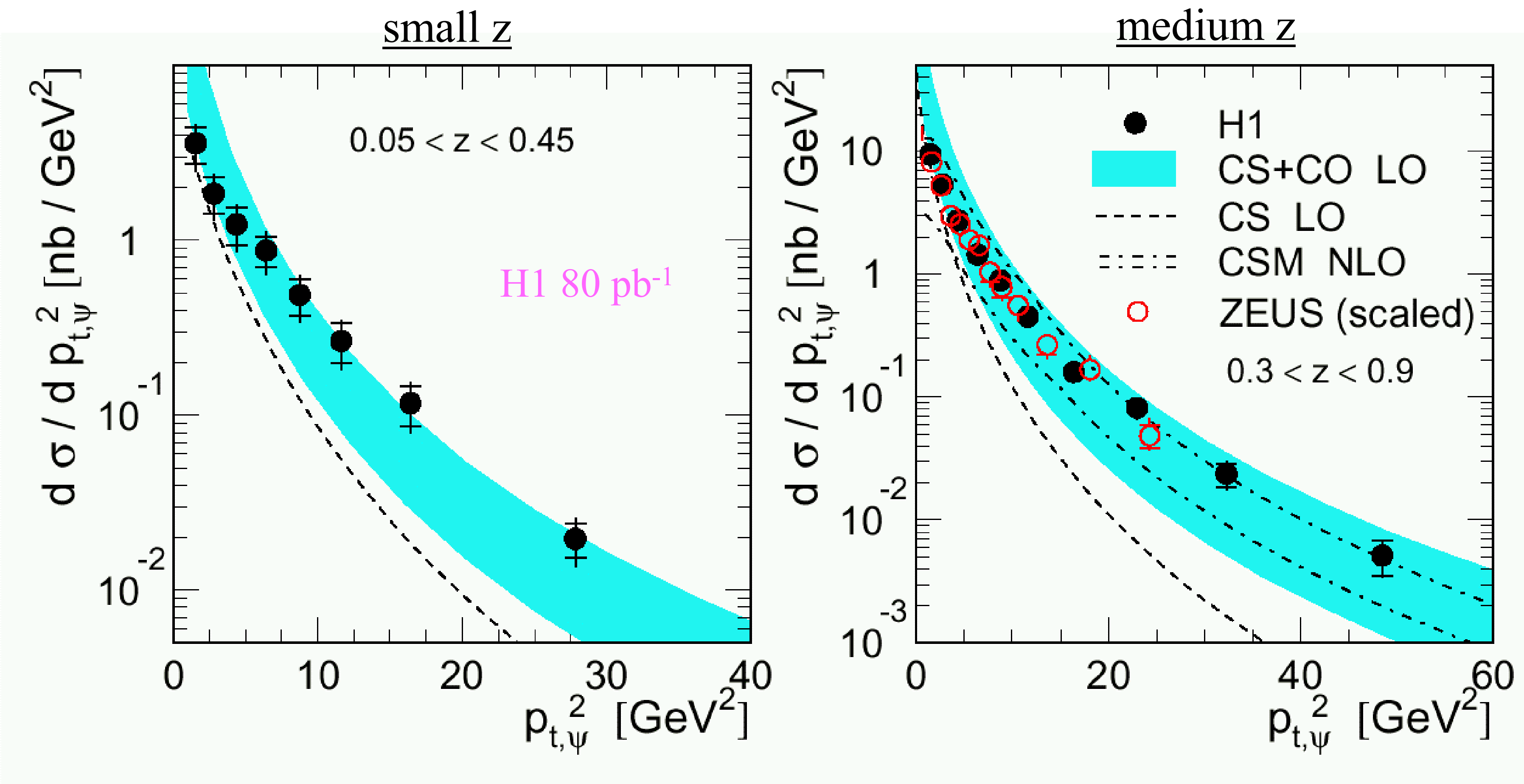
Errorbands: $1.3 \leq m_c \leq 1.5$ GeV
$0.1175 \leq \alpha_s(M_Z) \leq 0.1225$

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



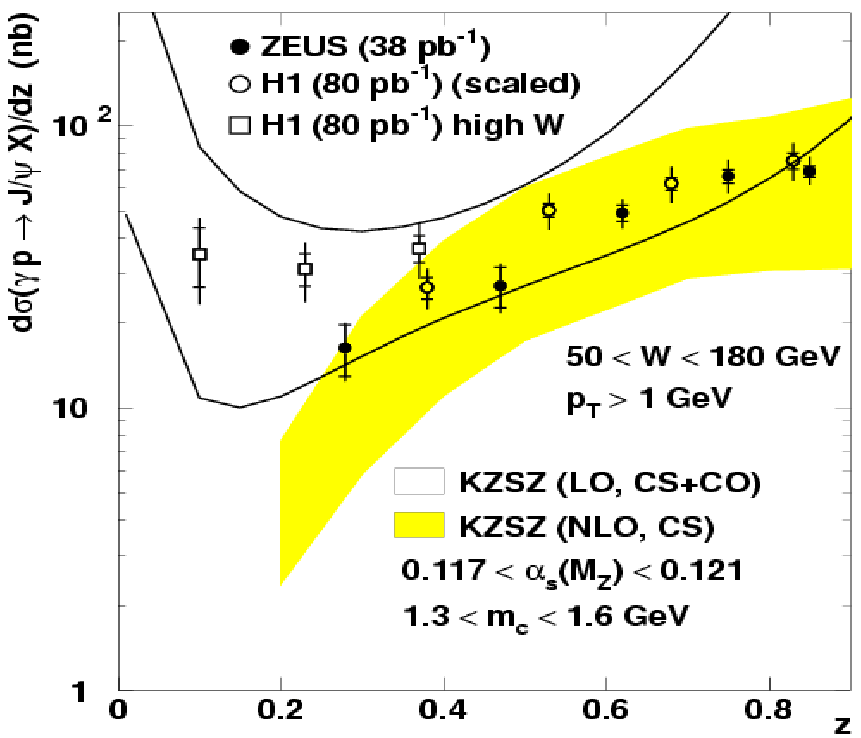
- p_T spectra similar at low and medium z
- NRQCD (including CS and CO): softer than data
  - Contributions from B decays in data?

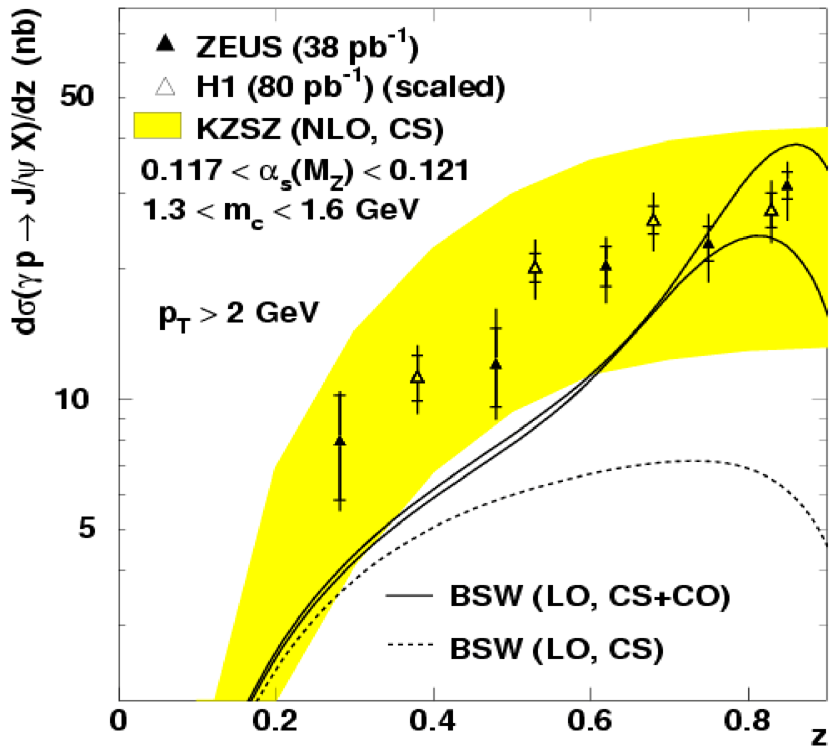
H1: EJ C25 (2002) 25
Zeus: EJ C27 (2002) 173

J/ψ Photoproduction: inelasticity

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

CO long-distance ME taken from fit to CDF data



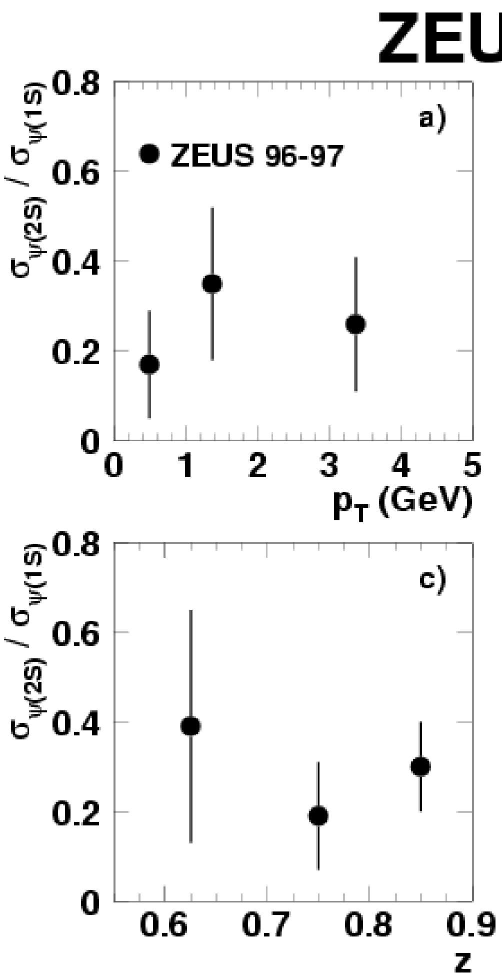


NLO CSM agrees with data; Theoretical uncertainties do not allow strong conclusions on CO

Left: NRQCD describes shapes (large LDME uncertainties)

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

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

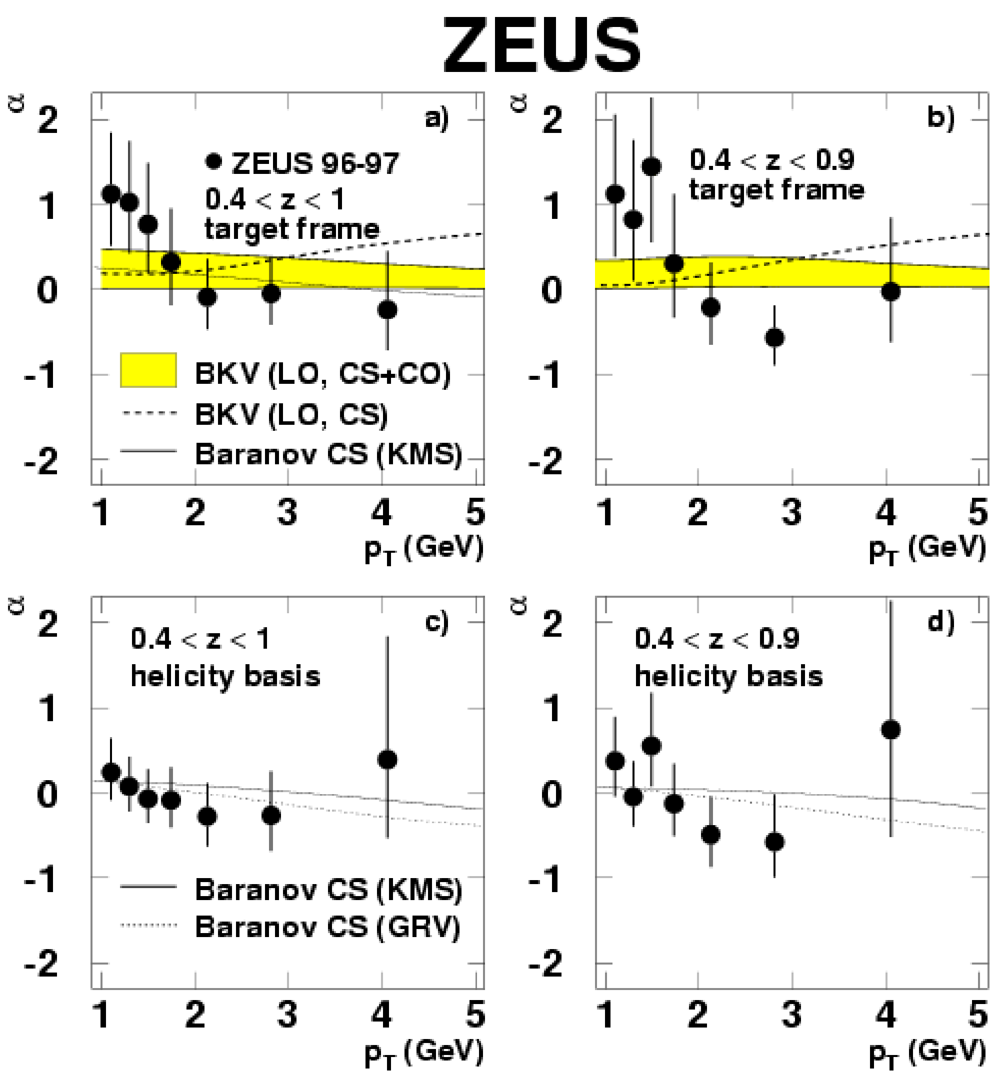


$$\sigma_{\psi(2S)} / \sigma_{\psi(1S)} = 0.33 \pm 0.10^{+0.01}_{-0.02}$$

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



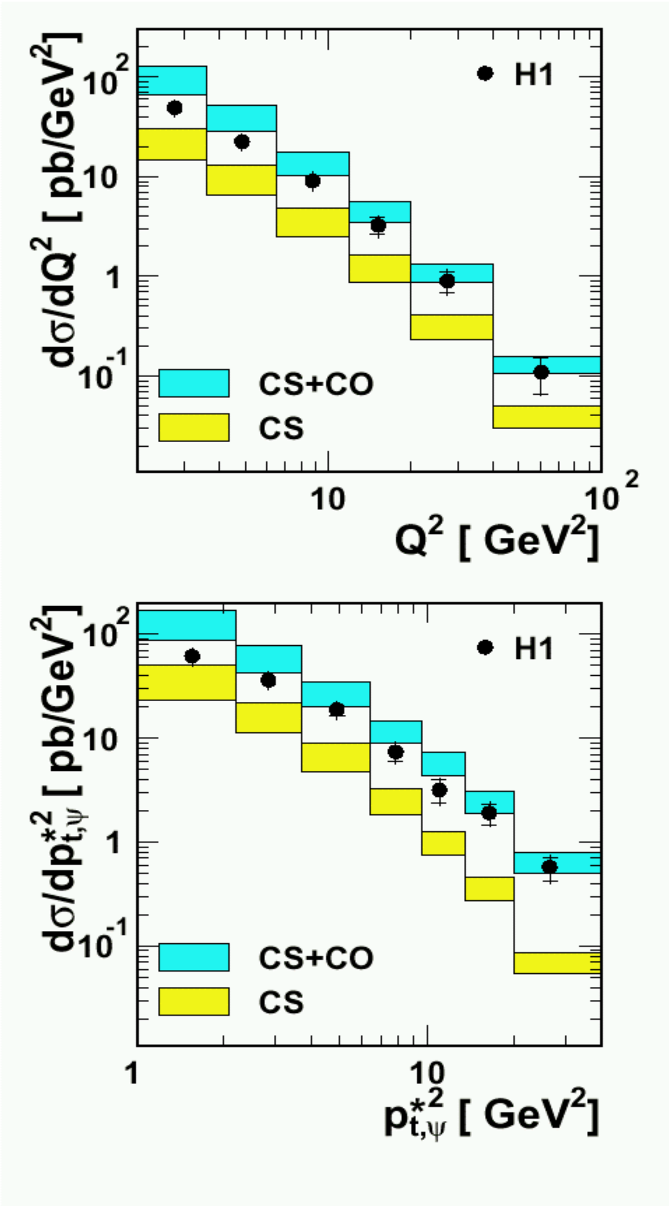
$dN/d\cos\theta^* \propto 1 + \alpha \cos^2\theta^*$

BKV – collinear calculations

Baranov – k_t-factorization

Statistics is not yet sufficient to discriminate between models

H1 - J/ψ Electroproduction



EJ C25 (2002) 41

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}

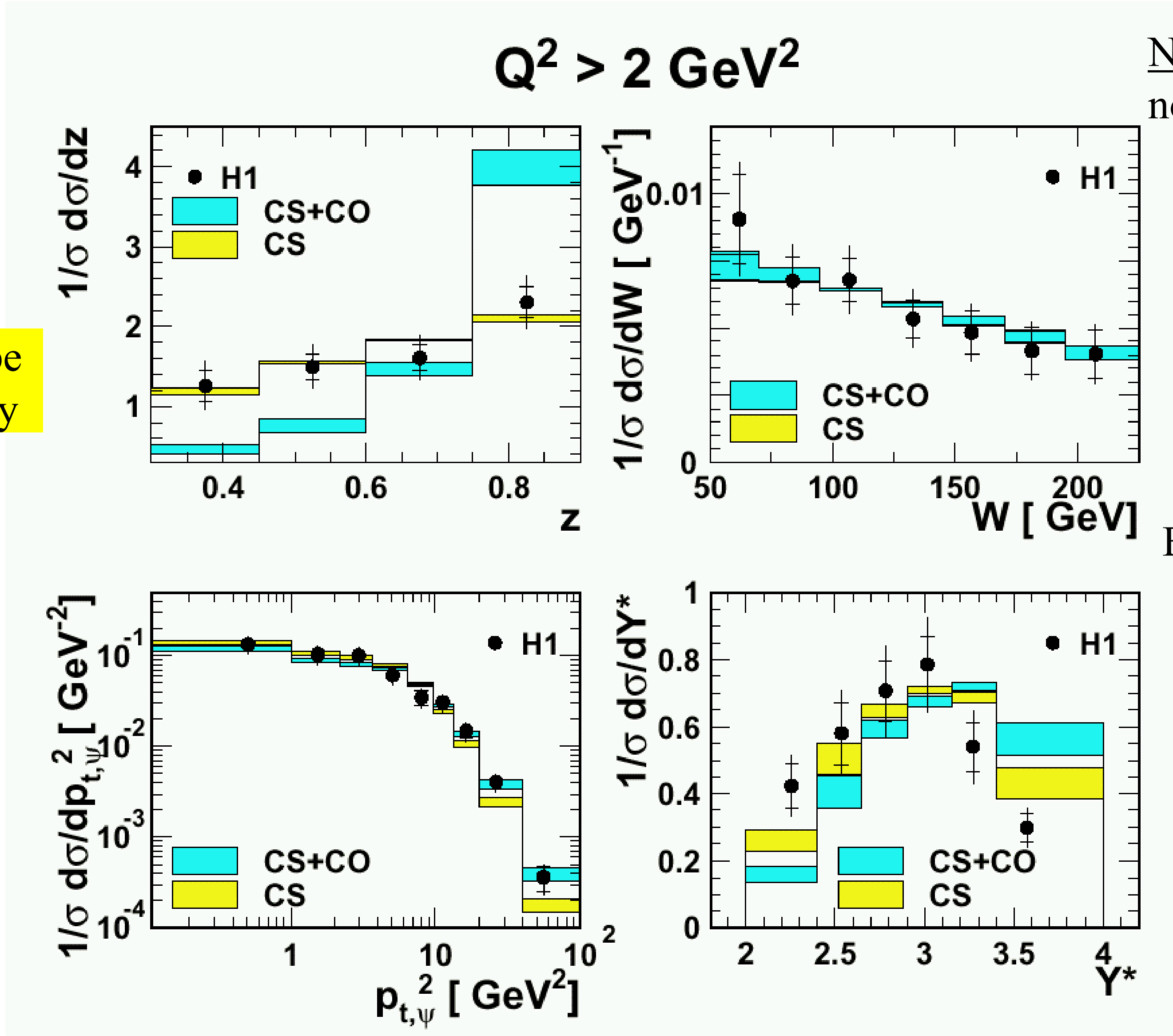
Theory: LO Colour Singlet Model
LO NRQCD (CS+CO)
(B.A.Kniehl, L.Zwirner, NP B621(2002) 337)

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

H1 - J/ψ Electroproduction



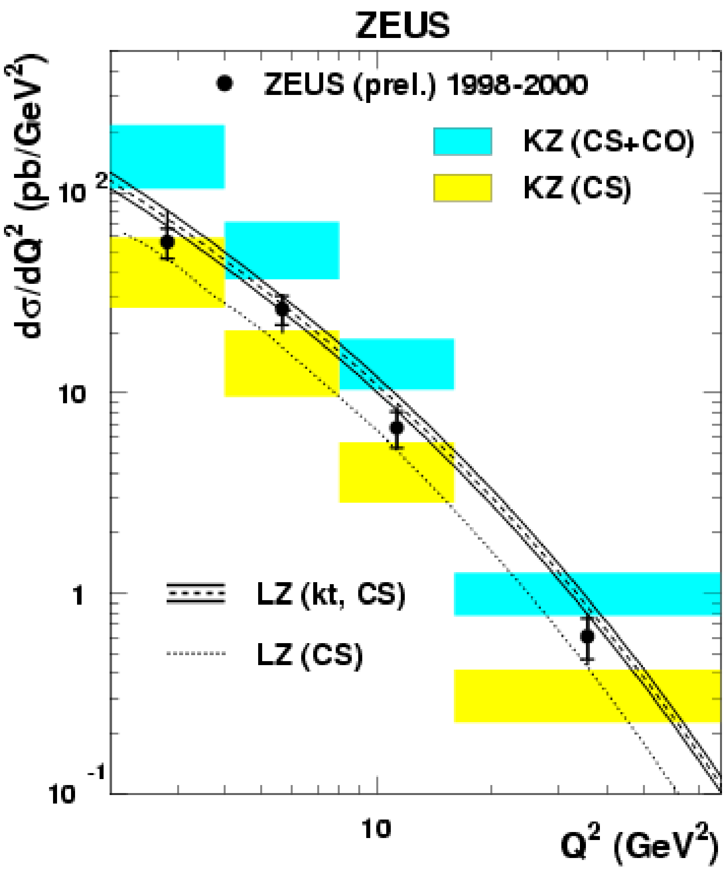
Note: Theory normalized to data

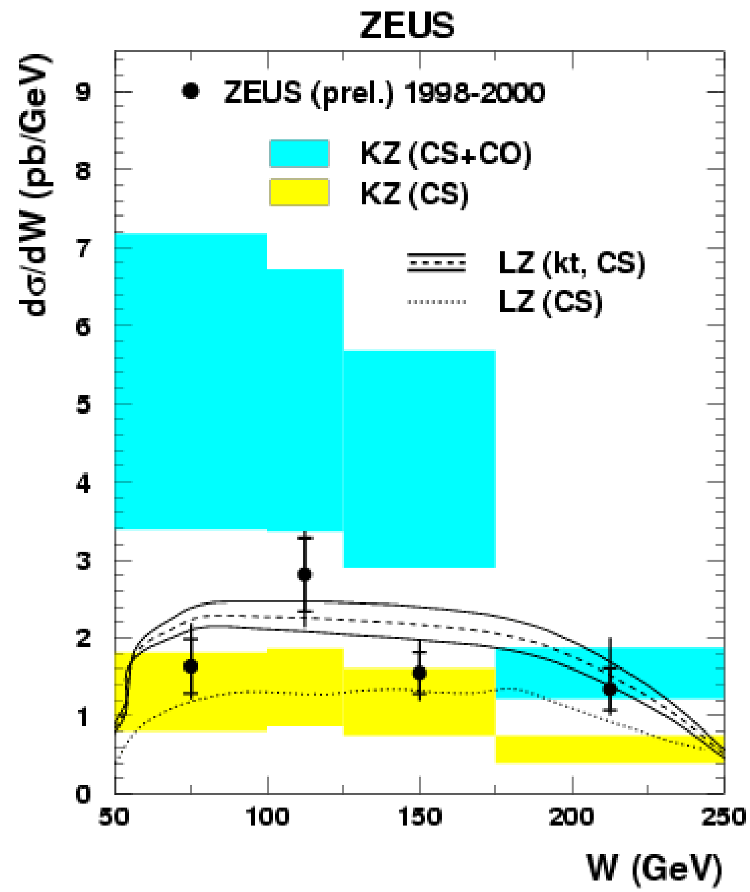
Large shape discrepancy

EJ C25 (2002) 41

Rapidity in γp CMS

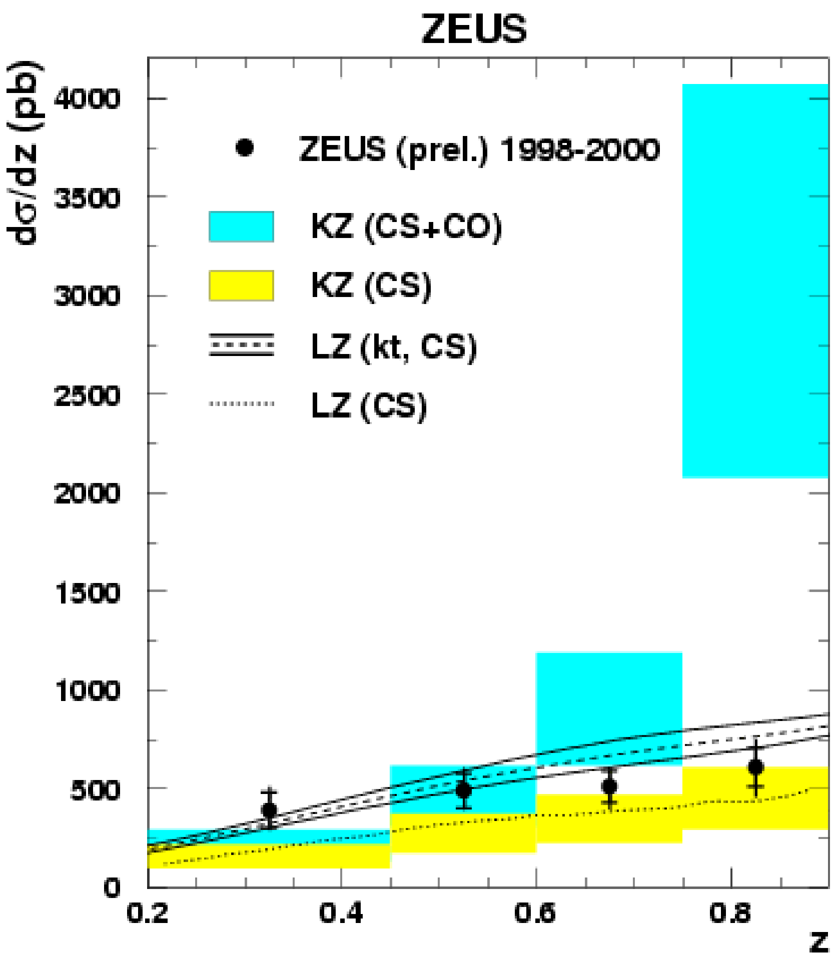
Zeus - J/ψ Electroproduction: Q^2 and W





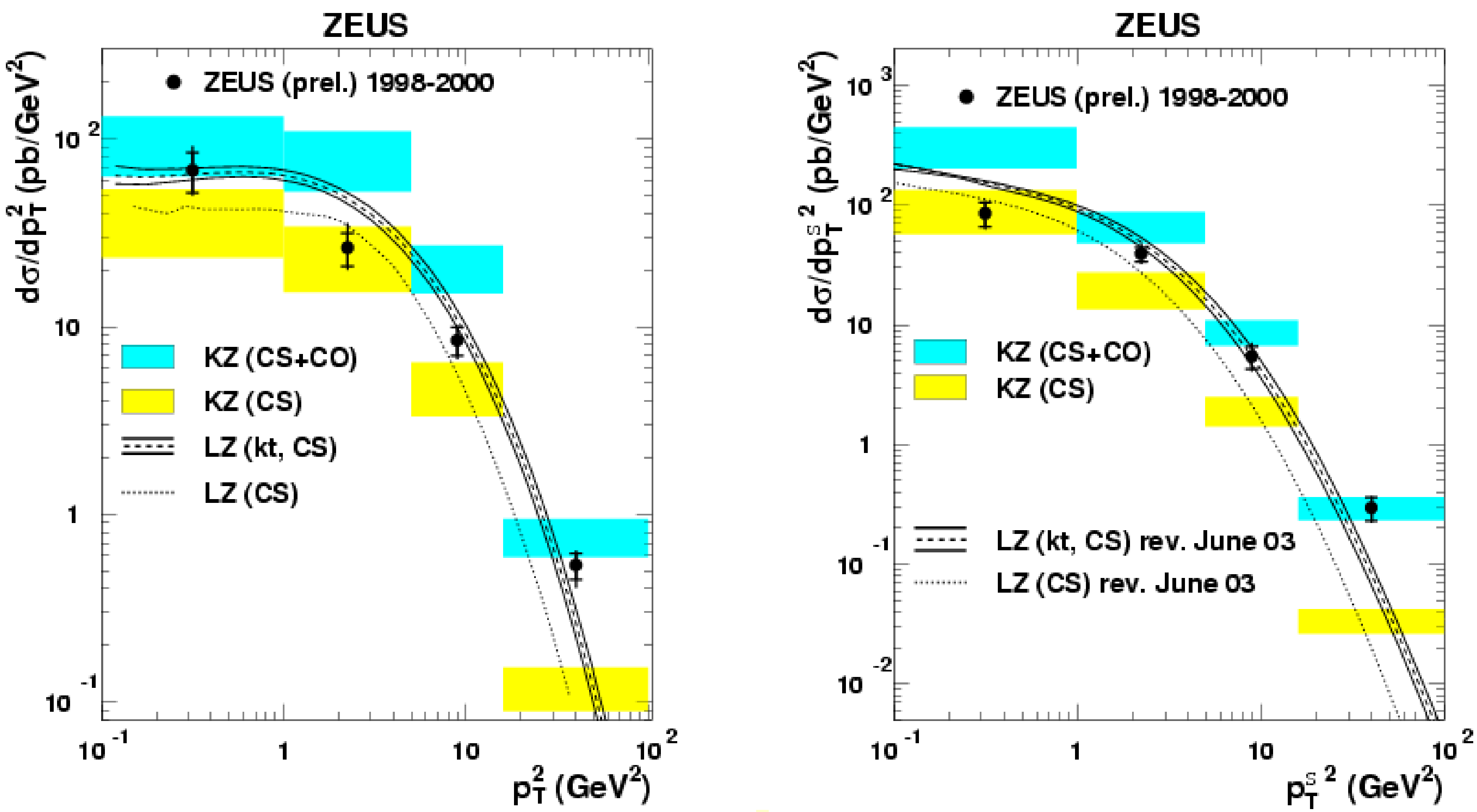
- KZ(CS) and LZ(CS): lower but consistent with data
- KZ(CS+CO): mostly overshoots data
- LZ(kt, CS): agrees with data

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}

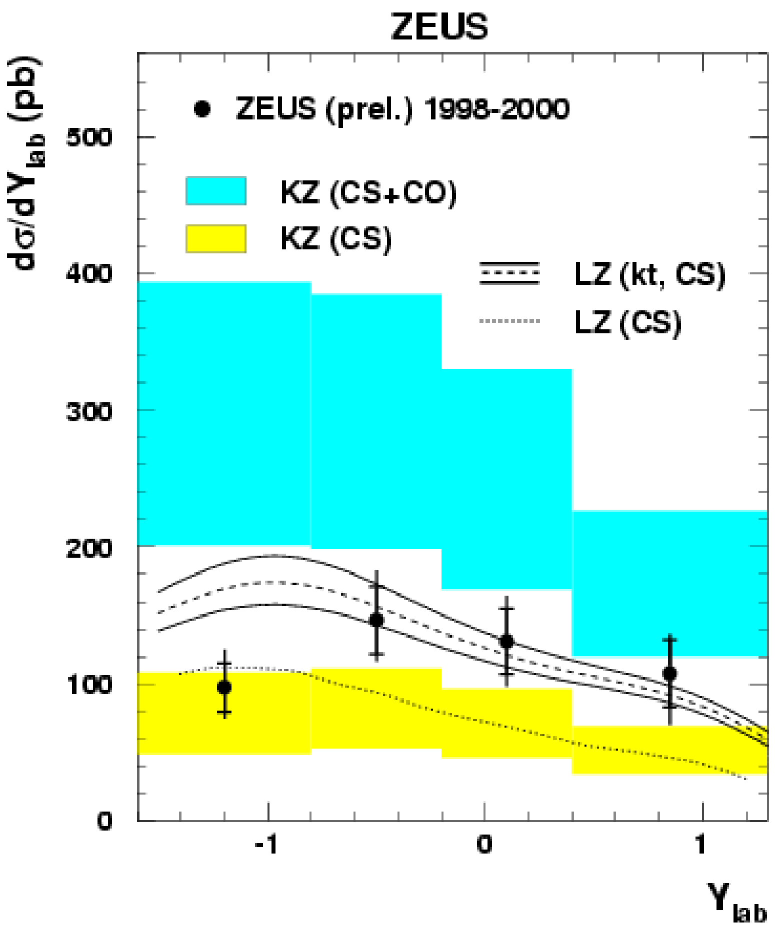


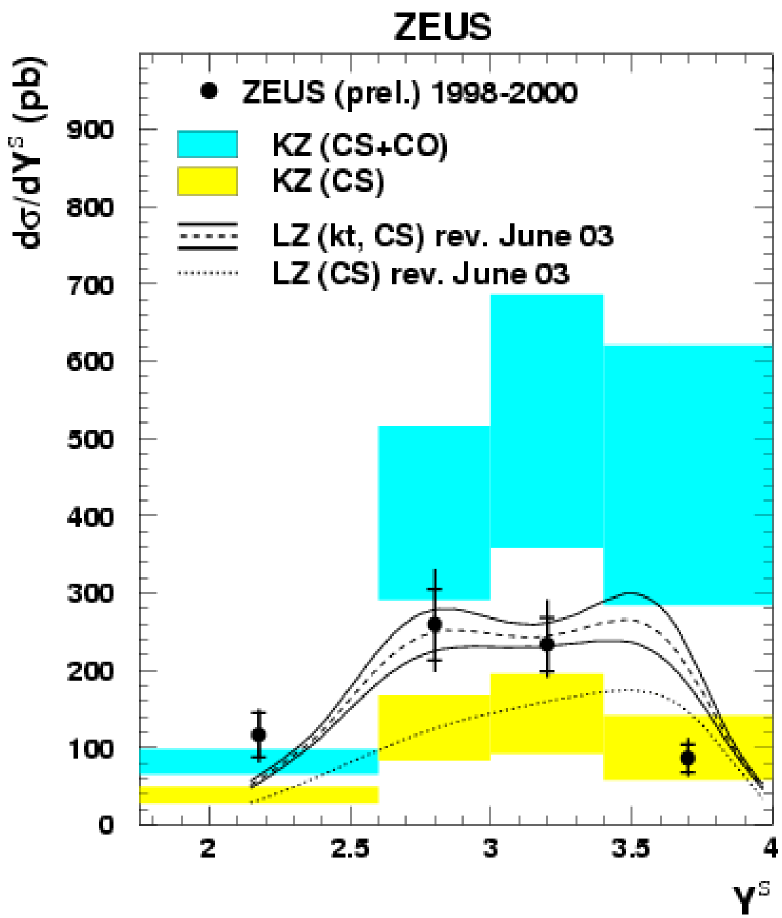
KZ (CS) and LZ(CS): too soft in comparison to data

KZ (CS+CO): overshoots data at low p_T^* values

LZ (kt, CS): too soft as well (NLO corrections?)

Zeus - J/ψ Electroproduction: rapidity

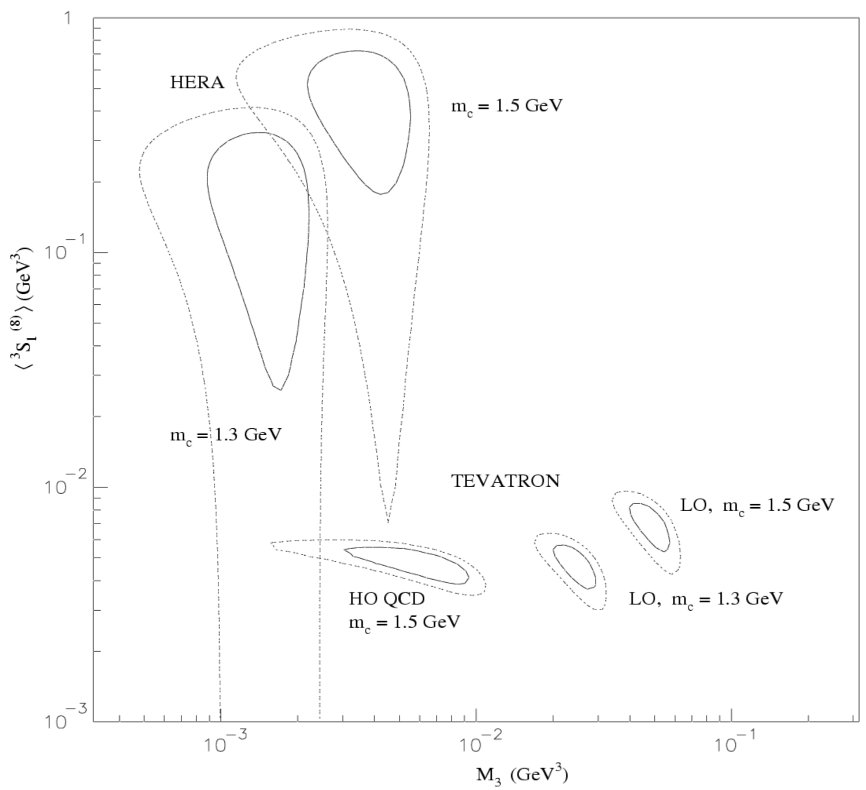




LZ (kt, CS) tends to be above the data in photon direction

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

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 Prospects

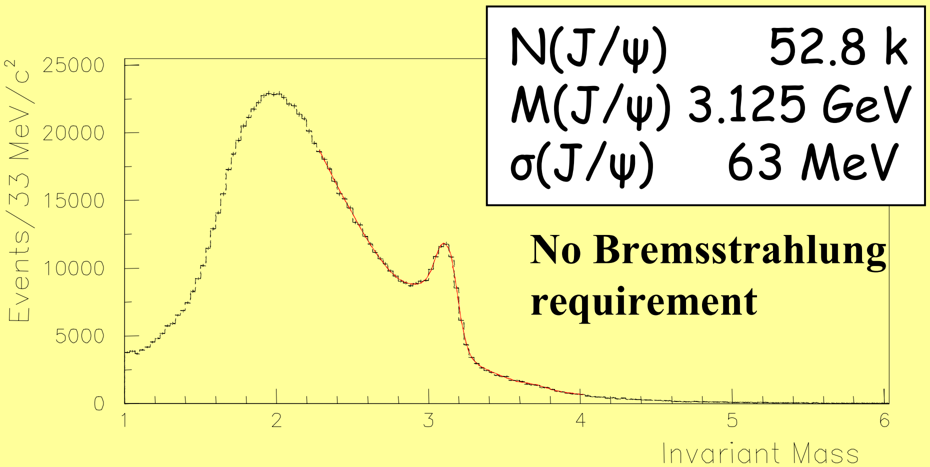
- "HERA I" running period ended in September 2000
  - Another > 50 pb^{-1} per experiment collected in 2000, giving a total of > 100 pb^{-1}
- Many analyses make use of the full data sets
- After the HERA upgrade:
  - $\int$**L dt** ~ 100 pb^{-1} per experiment expected by summer 2004
  - Polarized $e^{\pm}$ beams
- Various detector upgrades
  - ZEUS Silicon
  - New fast track trigger for H1
  - ...
- High Q^2/p_T will greatly benefit from increase in luminosity

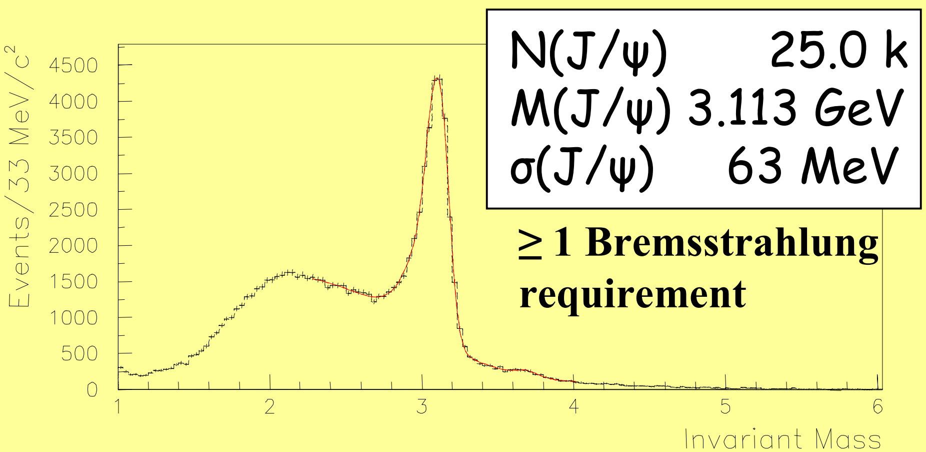
HERA-B

- HERA-B detector & trigger in good shape
  - Data taking : 30.October 2002 – 3.March 2003
  - 1200-1400 J/ψ per hour, 70% of available beam time used
  - ~ 300,000 triggered J/ψ ($e^+e^-/\mu^+\mu^-$)
  - ~ $210 \cdot 10^6$ Minimum bias events
- Analysis of 2002/03 data in progress

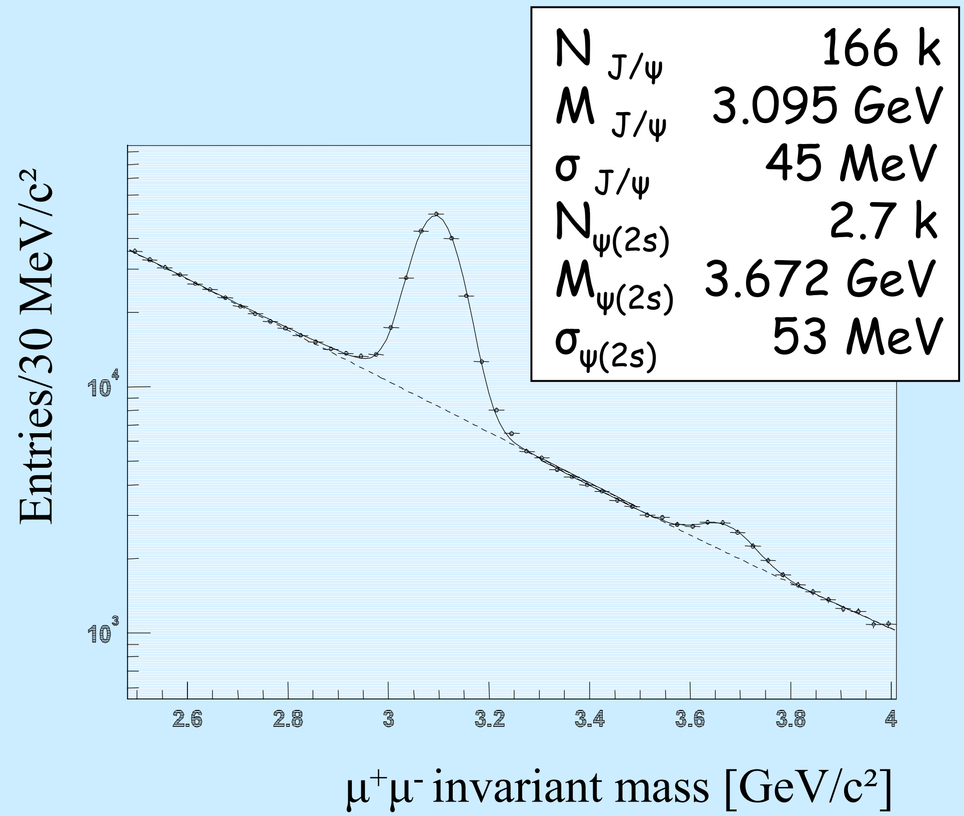
J/ψ - Statistics

$J/\psi \rightarrow e^+e^-$: 40 % of statistics





$J/\psi \rightarrow \mu^+\mu^-$: full statistics



Detached J/ψ Analysis

$J/\psi \rightarrow e^+e^-$

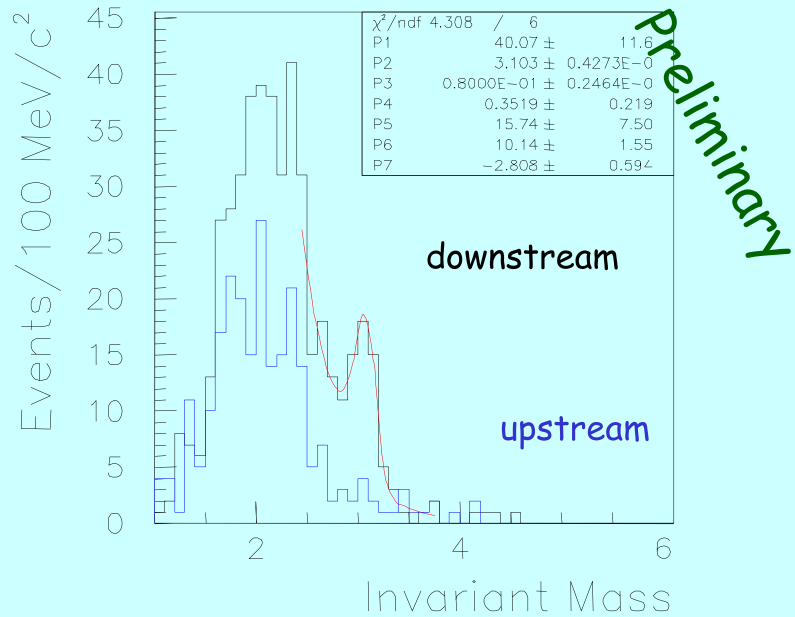
(40 % of statistics)

$\Delta z/\sigma_z > 10$
impact par. cut

No bremsstrahlung requirement

2000 :
$n_B = 8.6^{+3.9}_{-3.2}$

J/ψ = 40 ± 12



$J/\psi \rightarrow \mu^+\mu^-$

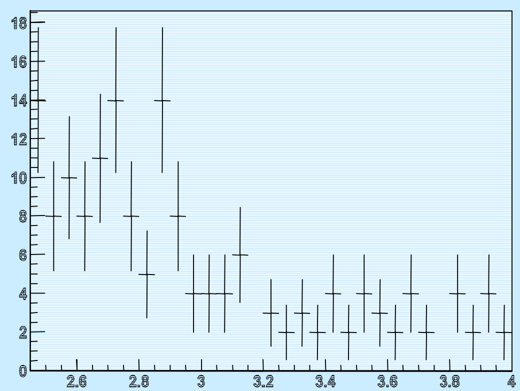
(60 % of statistics)

2000 :
$n_B = 1.9^{+2.2}_{-1.5}$

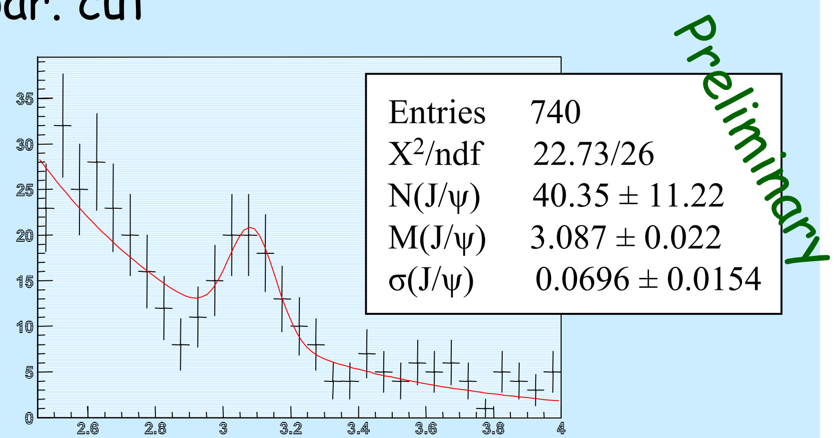
$\Delta z < -0.5$ cm

$\Delta z > 0.5$ cm

Impact par. cut



No upstream J/ψ

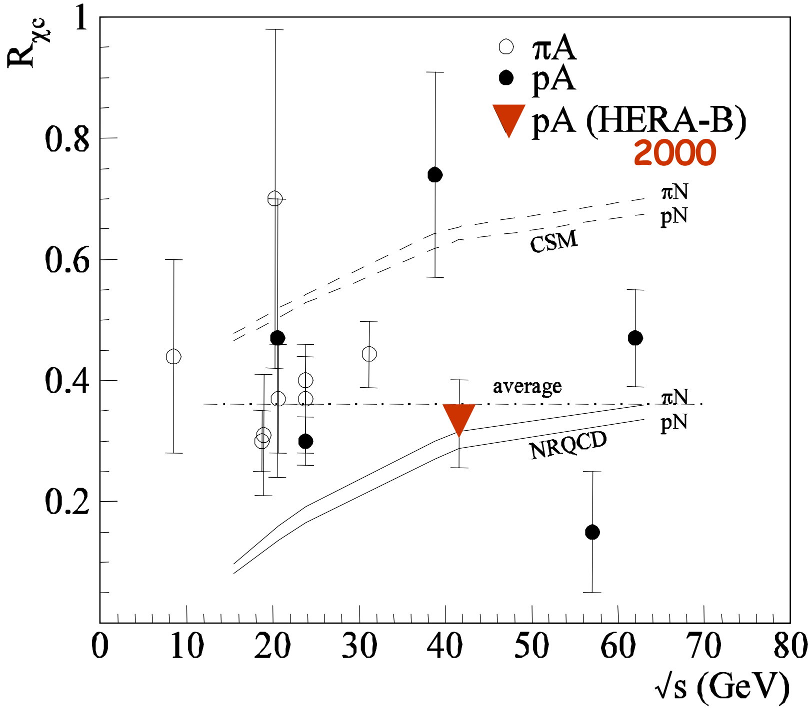


J/ψ = 40 ± 11

Charmonium Production : χ_c

Fraction of J/ψ produced via χ_c

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



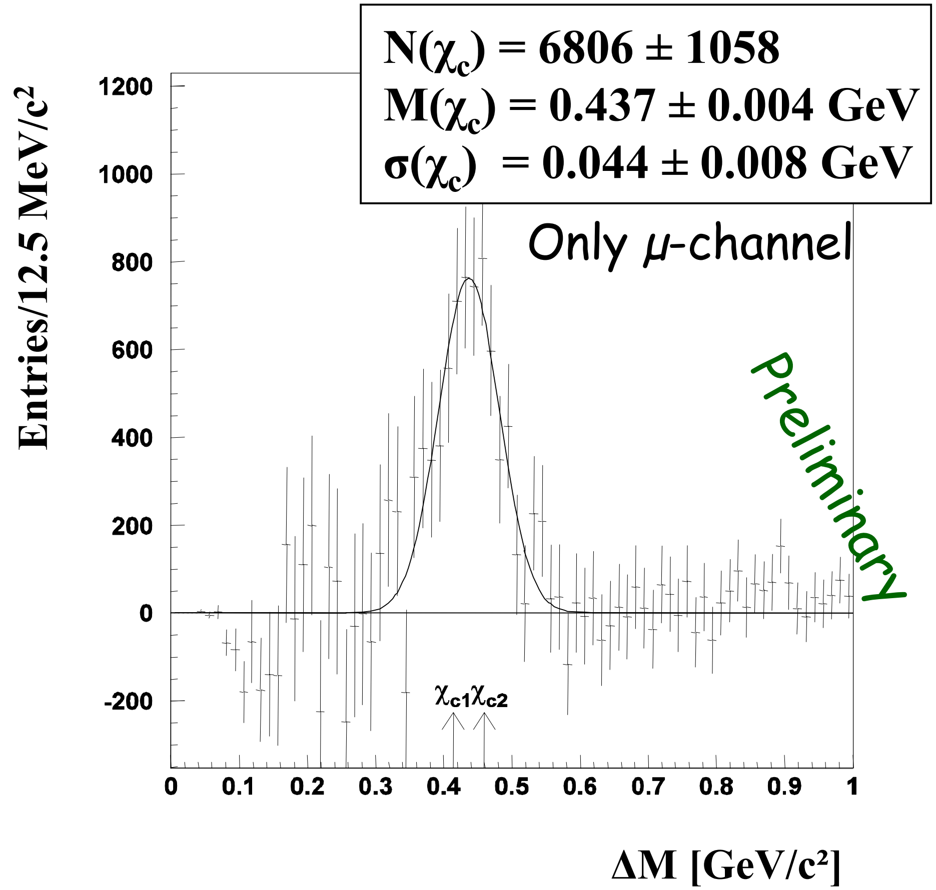
Measurement 2000 based on

380 ± 74 χ_c

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

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

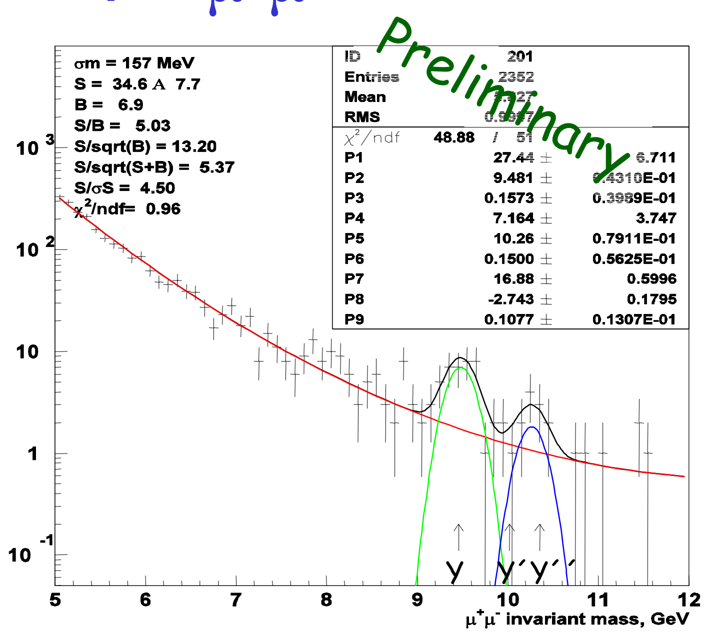
background subtracted



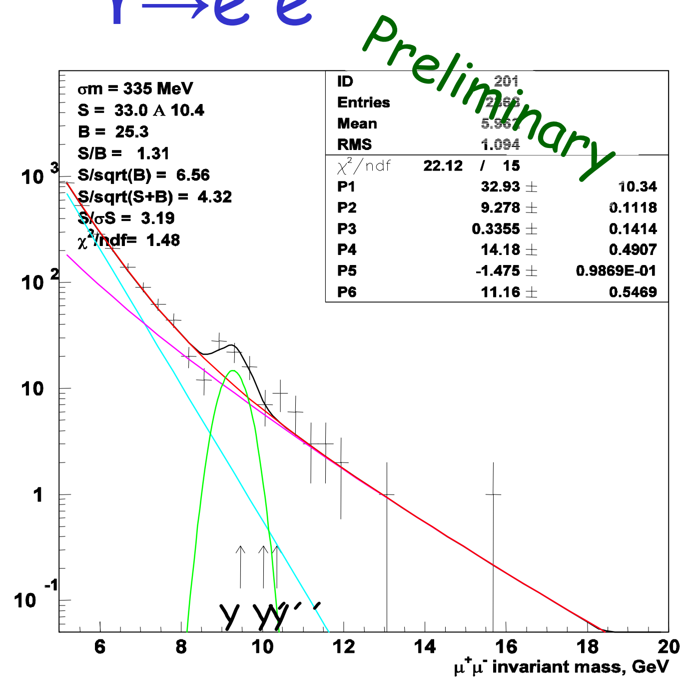
First measurement of χ_c suppression in nuclear matter possible !

Upsilon Production : σ(pA→ Υ)

Υ→μ⁺μ⁻



Υ→e⁺e⁻



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

Conclusions

- Tevatron Run I analyses done, most HERA-I analyses too
- Lots of results, many surprises
- Very fruitful interaction with theoretical developments
  - Non-relativistic QCD / colour octet contributions / ...
  - Soft Colour Interactions, Two Pomerons, ...
- Tevatron Run II will provide (1.4-9.0) fb^{-1} (14-90x statistics)
- HERA-II expected to deliver $\leq$ 1 fb^{-1} ($\leq$10x statistics, measure at larger Q^2, p_T, polarization)
- A lot of answers and surprises awaiting!!