PHOTON2000 29/8/2000

Recent Results on Charm Photoproduction

Don Hochman (Weizmann Institute)

on behalf of the ZEUS collaboration

O U T L I N E

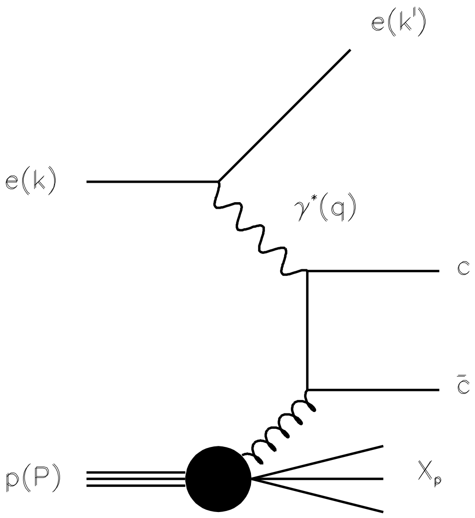
- $D_s \to \phi\pi$

- **Excited Charm Mesons**

- **Inelastic J/ψ Production**

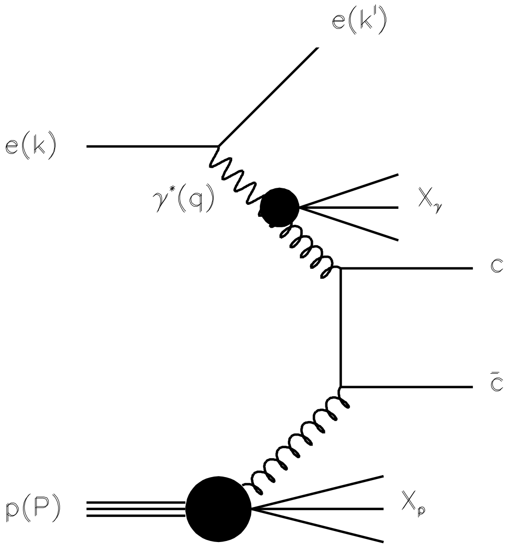
Open Charm Production at HERA

LO QCD contributions



direct–γ: γ–g fusion

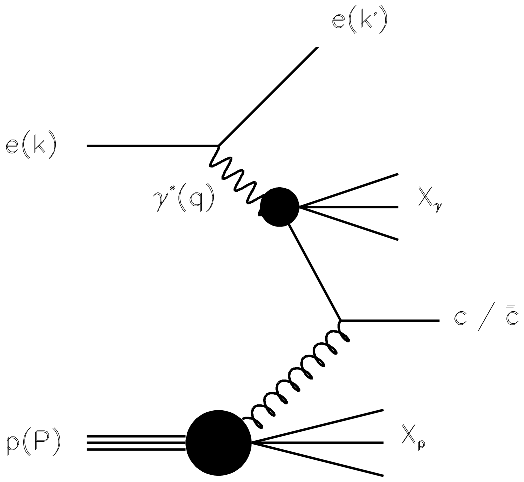
$\Rightarrow g^p(x, Q^2)$



resolved–γ: $g\ g \rightarrow c\ \bar{c}$

$\Rightarrow g^p(x, Q^2) \otimes g^\gamma(x, Q^2)$

suppressed with Q^2



resolved–γ: c excitation

Photoproduction: $Q^2 \simeq 0\,\mathrm{GeV}^2$

DIS $Q^2 > 1\,\mathrm{GeV}^2$

$D_s \to \phi\pi$

Previously ZEUS studied:

$D^{*+} \to D^0\pi^+ \to K^-\pi^+\pi^+$ Eur. Phys. J. C6(1999)67

Continue charm study with:

${D_s}^+ \to \phi\pi^+ \to K^+K^-\pi^+$ PRL B(481)2000 213-227

$1996 - 1997$ **Data:** $L = 38\mathbf{pb}^{-1}$

$\mathbf{BR}({D_s}^+ \to \phi\pi^+) = \mathbf{0.036 \pm 0.009}$

$\mathbf{BR}(\phi \to K^+K^-) = \mathbf{0.491 \pm 0.008}$

Kinematic Region:

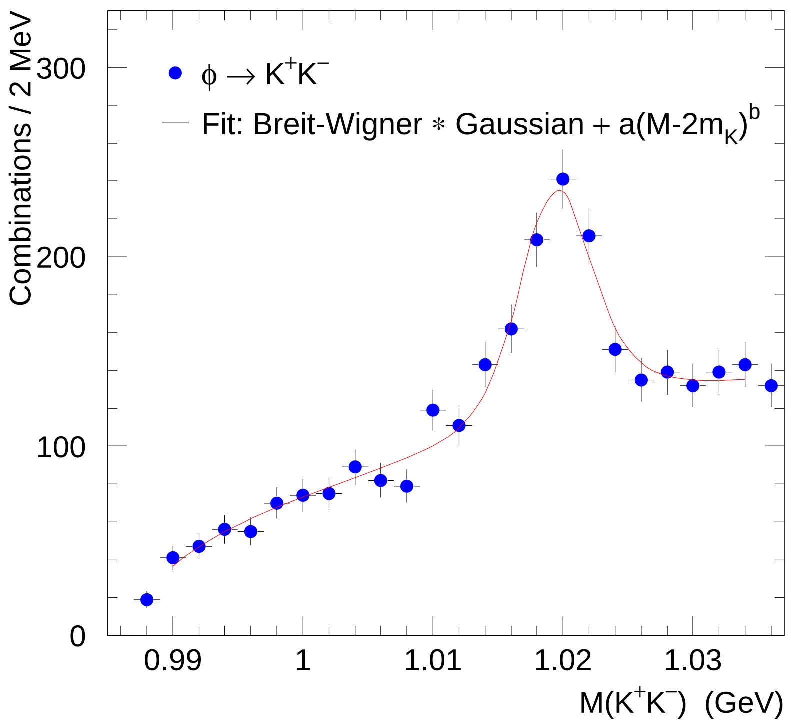
$Q^2 < 1\,\mathrm{GeV}^2$

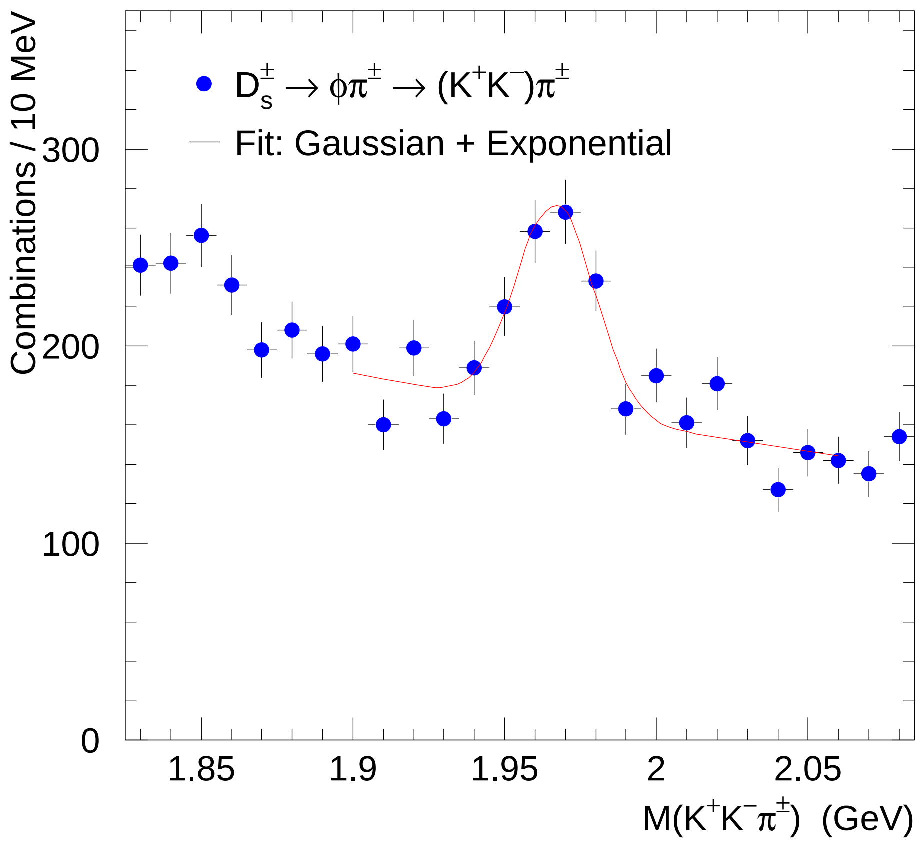
$130 < W_{\gamma p} < 280\,\mathrm{GeV}$

$3 < p_\perp^{D_s} < 12\,\mathrm{GeV}$

$|\eta^{D_s}| < 1.5$

$D_s \to \phi\pi$





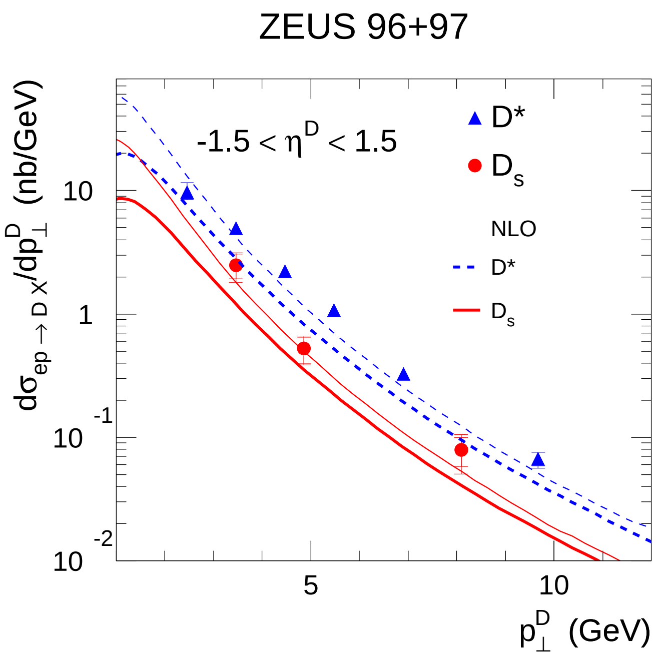
339 ± 48 D_s **Mesons**

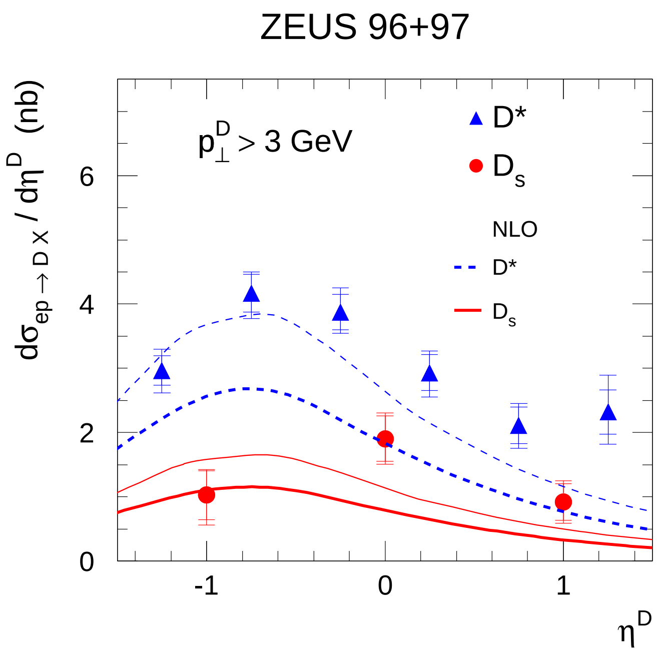
$$\sigma_{ep\to D_s X} = 3.79 \pm 0.59(stat)^{+0.26}_{-0.46}(syst) \pm 0.94(br)nb$$

$D_s \to \phi\pi$

NLO pQCD calculation

- **Fixed Order: (u, d, s) only active flavours in p and γ (Frixione et al.)**
  Charm produced by Boson-Gluon fusion.
  No explicit charm excitation component.
  (Which can be important in charm photoproduction.)
- **Peterson fragmentation:** $D_c(z) = N\frac{z(1-z)^2}{[(1-z)^2+\epsilon z]^2}$ $\quad z = \frac{p_{D^*}}{p_c}$
- **Lower curves** $\mu_R = \sqrt{m_c^2 + p_\perp^2}$, $\mu_F = 2\ m_\perp$, $m_c = 1.5\,GeV$
  Upper curves $\mu_R = 0.5\sqrt{m_c^2 + p_\perp^2}$, $\mu_F = 2\ m_\perp$, $m_c = 1.2\,GeV$
- **Parton density functions: MRSG (p); GRV–G HO (γ)**





Signal above NLO fixed order prediction

Most notably in forward η region

as is the case for the D^*

$D_s \to \phi\pi$

Fragmentation: Compare to e+ e-

$$\frac{\sigma_{ep\to D_s X}}{\sigma_{ep\to D^* X}} = 0.41 \pm 0.07(stat)^{+0.03}_{-0.05}(syst) \pm 0.10(br)$$

Consistent with e+ e-:

$$f(c \to D_s)/f(c \to D^*) = 0.43 \pm 0.04 \pm 0.11(br)$$

f's from recent compilation,[hep-ex/9912064,1999]

In above large branching ratio errors for $D_s \to \phi\pi$ enter. For comparison between e+ e- and e p they are the same so they can be ignored.

Strangeness Suppression Factor: $\gamma_s = P_s/P_{u,d}$

Using $\frac{\sigma_{ep\to D_s X}}{\sigma_{ep\to D^* X}}$ and PYTHIA:

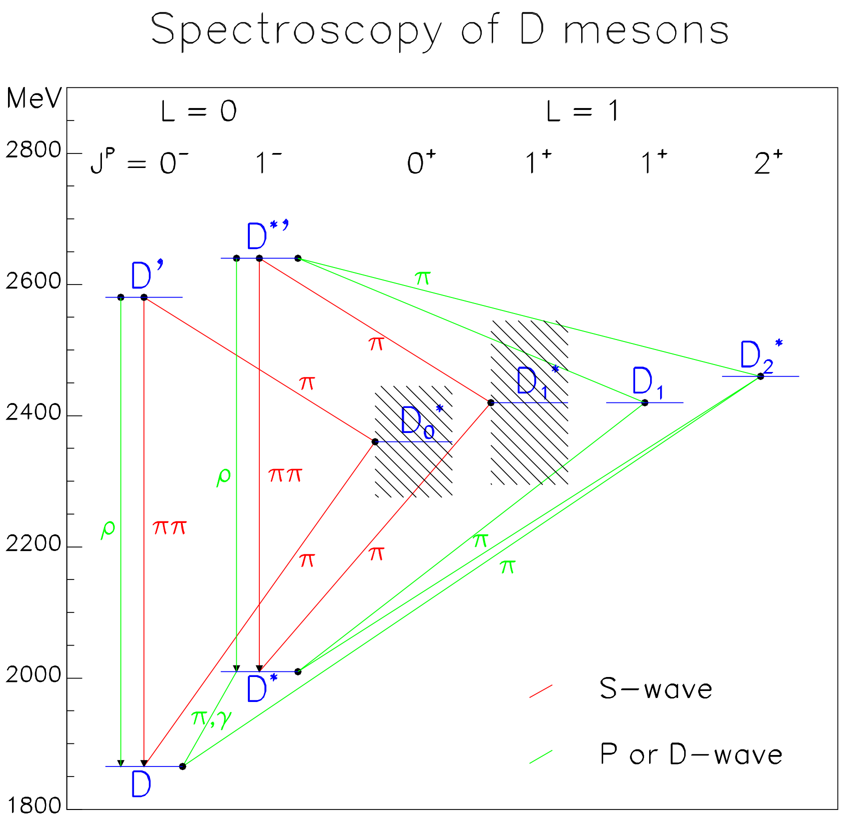
$$\gamma_s = \mathbf{0.27} \pm 0.04(stat)^{+0.02}_{-0.03}(syst) \pm 0.07(br)$$

For e+ e- $2f(c \to D_s^+)/[f(c \to D^0) + f(c \to D^+)]$
was used as an estimator for γ_s

$$\gamma_s = \mathbf{0.26} \pm 0.03(stat) \pm 0.07(br)(e+e-)$$

So there tends to be universality in charm fragmentation.

Excited Charm Mesons



In HQET $j = 3/2$ and $j = 1/2$ doublet P wave D states

2^+ state decays with L = 2(narrow)

Two 1^+ states decay with L = 0(wide),2(narrow)

PDG: Two orbital excited states: $D_1(2420)$,$D_2^{*0}(2460)$

Both can decay to $D^*\ \pi$

$D_1^0(2420)$ and $D_2^{*0}(2460)$ are narrow (around 20 MeV).

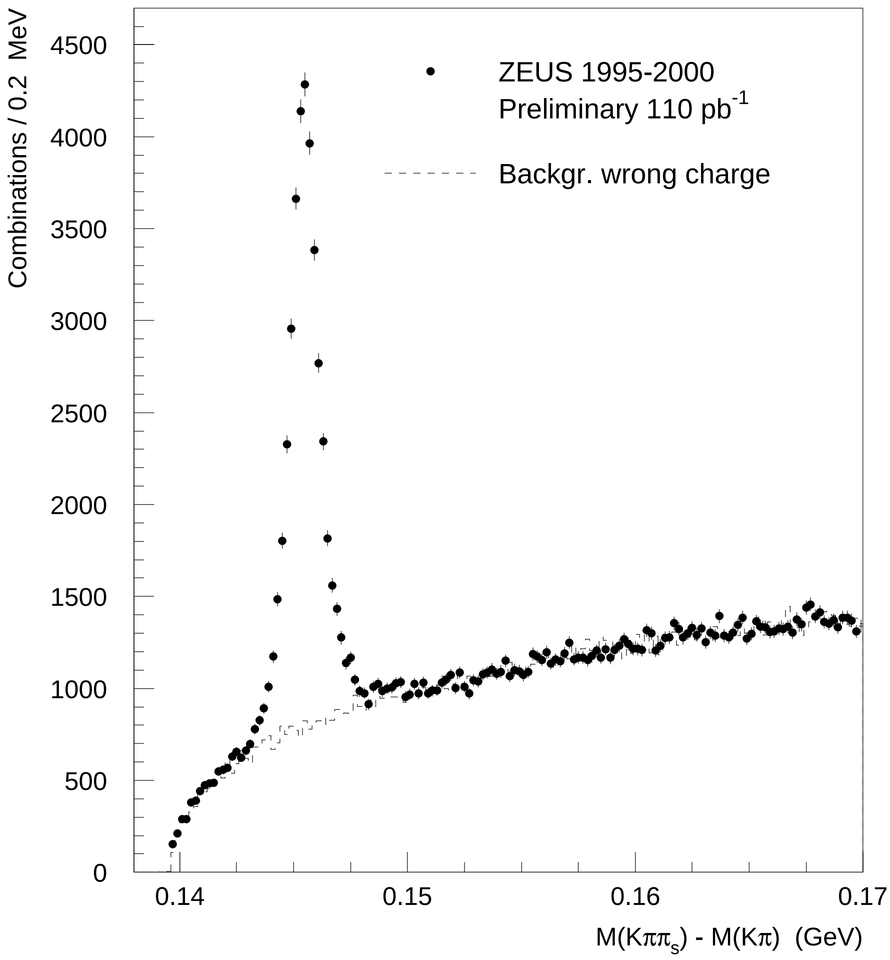
CLEO also see broad state: $M = 2461 MeV, \Gamma = 290 MeV$
They call this the S-wave D_1^* state. [Nucl.Phys.A663(2000)647]

Excited Charm Mesons

$L = 110\, pb^{-1}$

Photoproduction and DIS together

$P_\perp^{D^{*\pm}} > 2\,\mathrm{GeV}$, $|\eta^{D^{*\pm}}| < 1.5$



In the mass windows:

$$1.83 < M(K,\pi) < 1.90\,\mathrm{GeV}$$

$$144.0 < M(K,\pi,\pi_s) - M(K,\pi) < 147.0\,\mathrm{MeV}$$

Obtain

$$N(D^{*\pm}) = 27286 \pm 232$$

Excited Charm Mesons

Add extra track(π_4) to D^* candidate such that total charge is 0

$$M(K,\pi,\pi_s,\pi_4) - M(K,\pi,\pi_s) + M(D^*)(2.010\,\mathrm{GeV})$$

Fit D_1^0 and D_2^{*0} to Breit-Wigner shapes convoluted with a Gaussian

Breit-Wigner masses,widths fixed to PDG

Resolution: $5\,\mathrm{MeV}$ from MC simulation

Fit done by unbinned likelihood method

Background is described with:

$$x^\alpha \cdot exp(-\beta \cdot x + \gamma \cdot x^2)$$

$$x = M(K,\pi,\pi_s,\pi_4) - M(K,\pi,\pi_s) - m_\pi$$

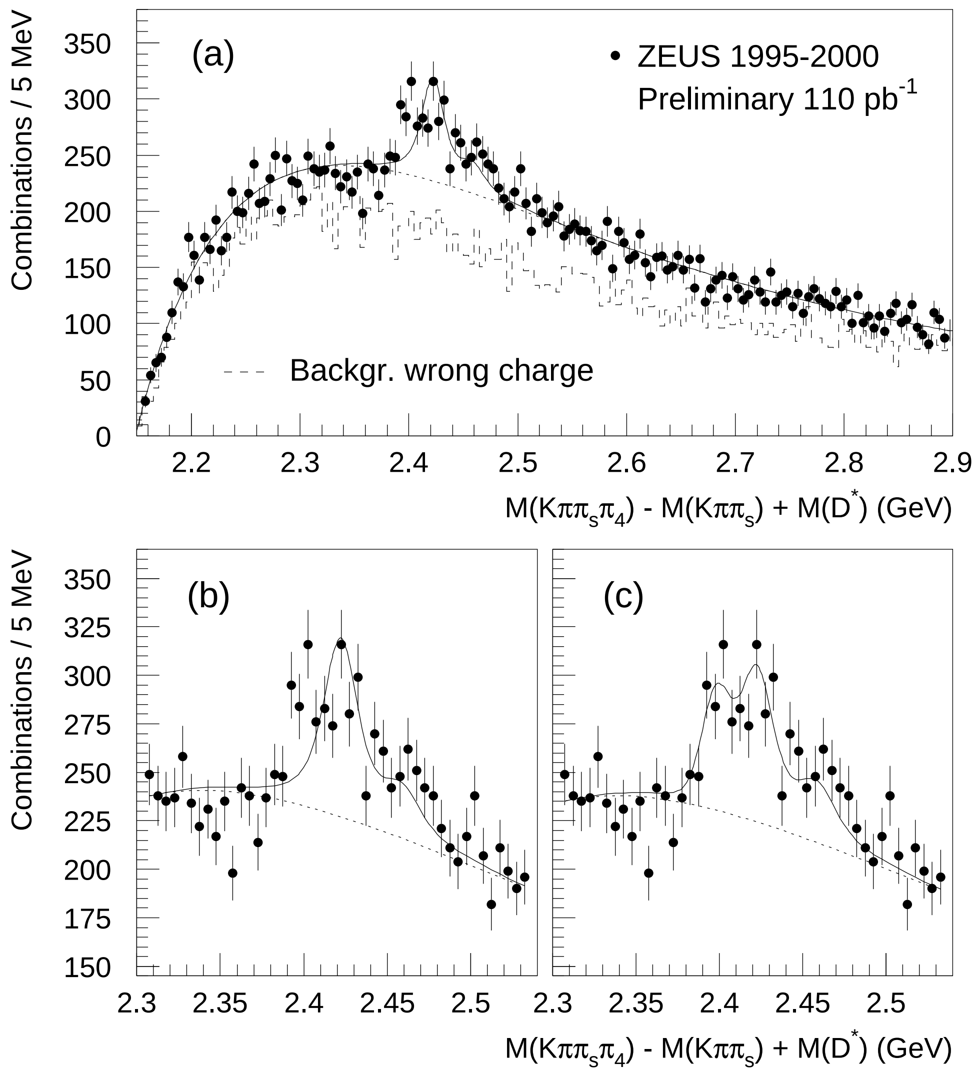
Fold in helicity spectrum for D_1^0 and D_2^{*0}

α: angle between π_4 and π_s in D^* rest frame

$$\frac{dN}{d\cos\alpha} \propto 1+3\cos^2\alpha \quad (1^+ \text{ state} \quad \mathrm{j} = 3/2 \text{ doublet})$$

$$\frac{dN}{d\cos\alpha} \propto 1-\cos^2\alpha \quad (2^+ \text{ state} \quad \mathrm{j} = 3/2 \text{ doublet})$$

Excited Charm Mesons



See enhancement for charge 0 system only

$N(D_1^0) = 526 \pm 65, N(D_2^{*0}) = 203 \pm 60$

Excess of events near M = 2.4 GeV

Including an extra resonance (Gaussian)(c)

- 211 ± 49 **entries**
- **Mass:** $2398.1 \pm 2.1(\text{stat.})^{+1.6}_{-0.8}(\text{syst.})\text{MeV}$
- **Width consistent with resolution**

Excited Charm Mesons

Fraction of D^* from D_1^0 and D_2^{*0}

Acceptance Corrected using Pythia

$$R_{D_1^0 \to D^{*\pm}\pi^\mp / D^{*\pm}} = 3.40 \pm 0.42(stat.)^{+0.78}_{-0.63}(syst.)\%$$

$$R_{D_2^{*0} \to D^{*\pm}\pi^\mp / D^{*\pm}} = 1.37 \pm 0.40(stat.)^{+0.96}_{-0.33}(syst.)\%$$

Systematic positive $R_{D_2^{*0} \to D^{*\pm}\pi^\mp / D^{*\pm}}$ error dominated by difference with fit without helicity information

Extrapolate to full kinematic region,using

- $f(c \to D^{*+}) = 0.235 \pm 0.007 \pm 0.007$
- $\Gamma(D_2^{*0} \to D^+\pi^-)/\Gamma(D_2^{*0} \to D^{*+}\pi^-) = 2.3 \pm 0.6$
- **Isospin Conservation**

	$f(c \to D_1^0)$ [%]	$f(c \to D_2^{*0})$ [%]
ZEUS Prelim.	$1.46 \pm 0.18^{+0.33}_{-0.27} \pm 0.06$	$2.00 \pm 0.58^{+1.40}_{-0.48} \pm 0.41$
CLEO	1.8 ± 0.3	1.9 ± 0.3
OPAL	2.1 ± 0.8	5.2 ± 2.6
ALEPH Prelim.	1.6 ± 0.5	4.7 ± 1.0
DELPHI Prelim.	1.9 ± 0.4	4.7 ± 1.3

Search For Radially Excited D^* States

Radial excitations predicted above $2500\,\mathrm{MeV}$

DELPHI see a peak in $D^{*+}\pi^+\pi^-$ **at** $M = 2637\,\mathrm{MeV}, \Gamma < 15\,\mathrm{MeV}$
[PLB 426 (1998) 231]

OPAL and CLEO do not see this.
[OPAL PN 352,CLEO hep-ex 9901008]

What about HERA?

Add $\pi^+\pi^-$ **pair** (π_4, π_5) **to** D^* **candidate**

$p_\perp(\pi) > 0.125\,\mathrm{GeV}$ **for extra pions**

$M(K, \pi, \pi_s, \pi_4, \pi_5) - M(K, \pi, \pi_s) + M(D^*)$

Background is described with:

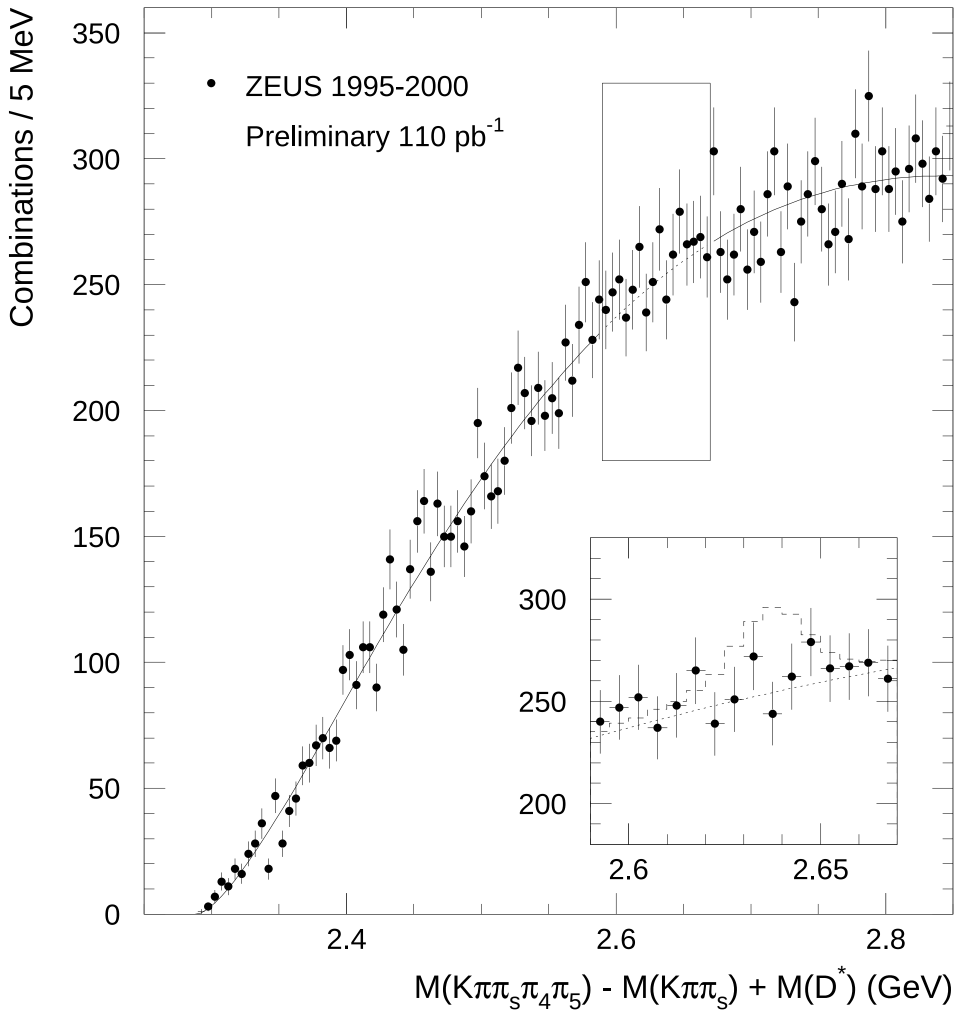
$x^\alpha \cdot e^{(-\beta \cdot x)}$

$x = M(K, \pi, \pi_s, \pi_4, \pi_5) - M(K, \pi, \pi_s) - 2 * m_\pi$

Look in mass window $2590 < M < 2670\,\mathrm{MeV}$

Fit background outside window,and interpolate

Search For Radially Excited D^* States



Signal: 91 ± 75 **entries**

$$R_{D^{*\prime +} \to D^{*+}\pi^+\pi^- / D^{*+}} < 2.3\% \quad (95\% \quad C.L.)$$

Extrapolate to full kinematic range

And use value for $f(c \to D^*)$:

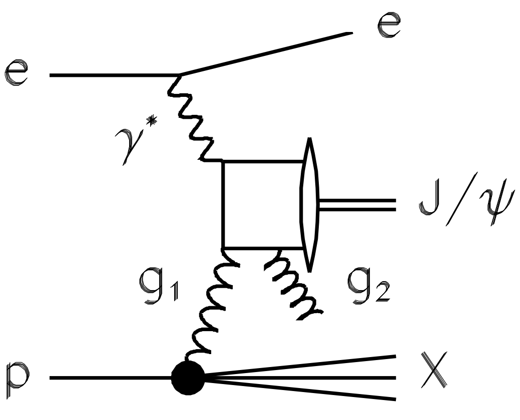
$$f(c \to D^{*\prime +}) \cdot B_{D^{*\prime +} \to D^{*+}\pi^+\pi^-} < 0.7\% \quad (95\% \quad C.L.)$$

Compare to 1.2% **OPAL (ICHEP 98)**

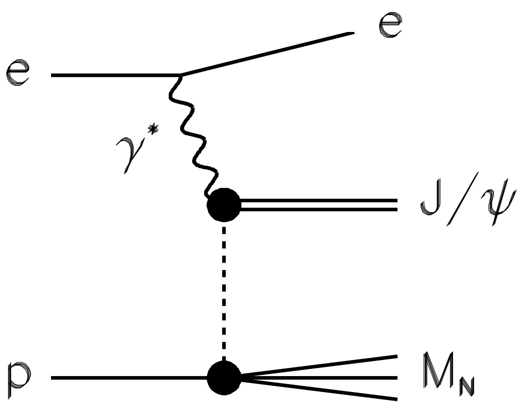
INELASTIC J/ψ

$z = P \cdot p^{J/\psi} / P \cdot q = \frac{E_{J/\psi}}{E_{\gamma^*}}$**(p rest frame)**

$z \simeq \frac{(E-p_z)_{J/\psi}}{\Sigma_i (E-p_z)_i}$**(lab) (no scattered e^+)**

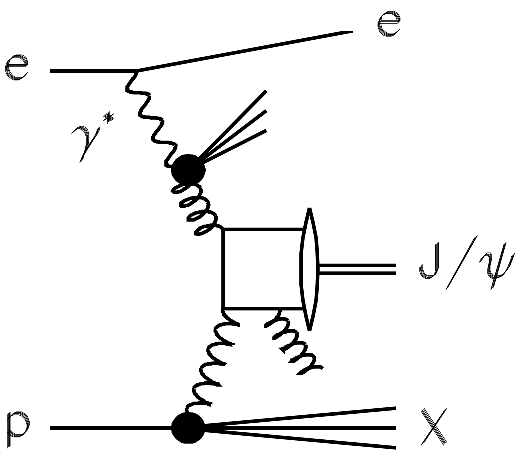


(a)

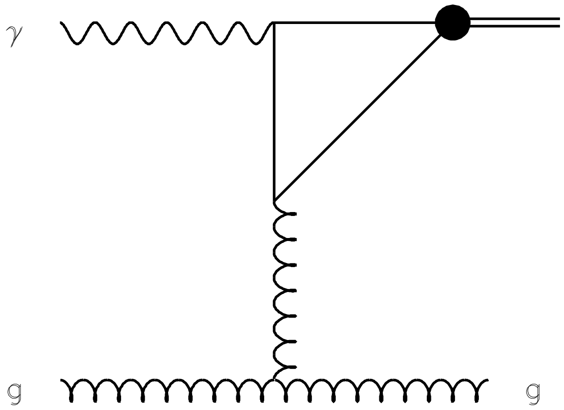


(b)

Colour Singlet **Colour Singlet**



(c)



(d)

Colour Singlet **Colour Octet**

(a) Direct photon(BGF) (medium z)

(b) Diffractive (large z)

(c) Resolved photon (small z)

(d) Direct photon

INELASTIC J/ψ

$1996 - 1997$ **Data:** $L = 38\mathbf{pb}^{-1}$

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

Kinematic Region:

$0.4 < z < 1.0\,\mathrm{GeV}$

$50 < W_{\gamma p} < 180\,\mathrm{GeV}$

$\Sigma_i(E - p_z)_i < 20\,\mathrm{GeV}$ **insures** $Q^2 < 1\,\mathrm{GeV}^2$

z **cut removes high background,resolved component**

Require $E > 1\,\mathrm{GeV}$ **in** 35° **cone along** p **direction**

This cut removes most diffractive events.

$0.4 < z < 0.9\,\mathrm{GeV} \Rightarrow$ **further reduce diffraction**

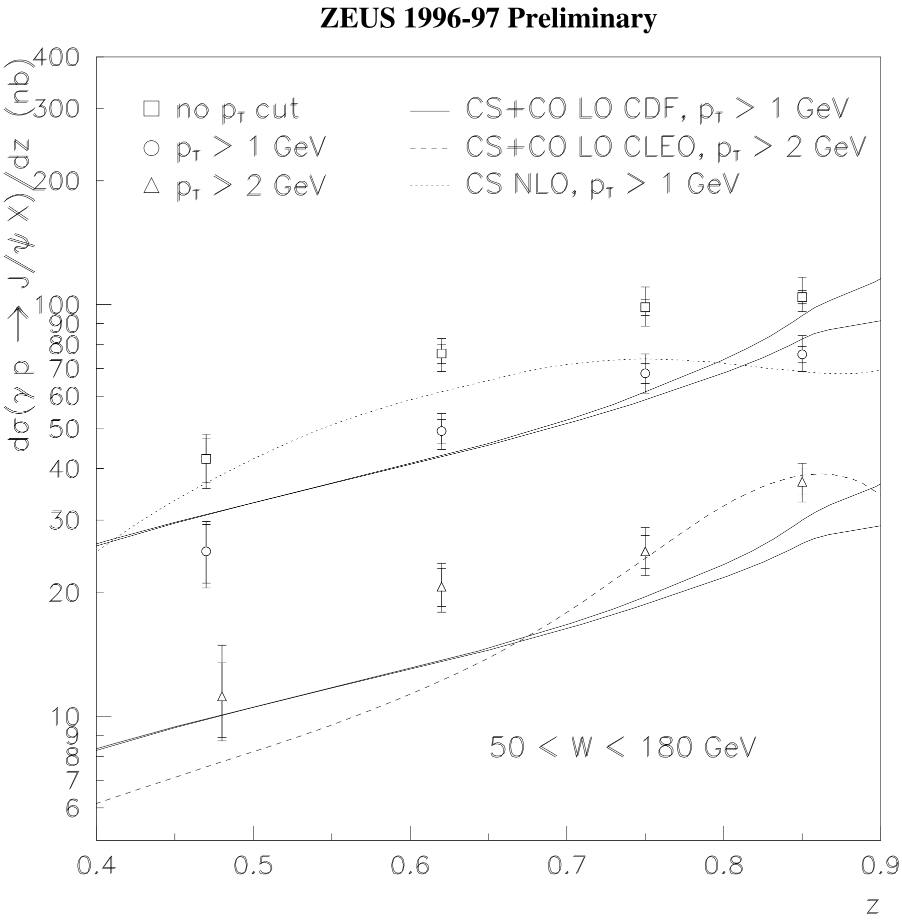
HERWIG: BGF in colour singlet,EPSOFT: Diffr. part

12% **diffractive background,**$15\%\,\psi'$ **background**

INELASTIC J/ψ

Colour Octet need matrix elements from experiment

Solid curve difference: Matrix element uncertainty



For $p_\perp > 1\,\mathrm{GeV}$:

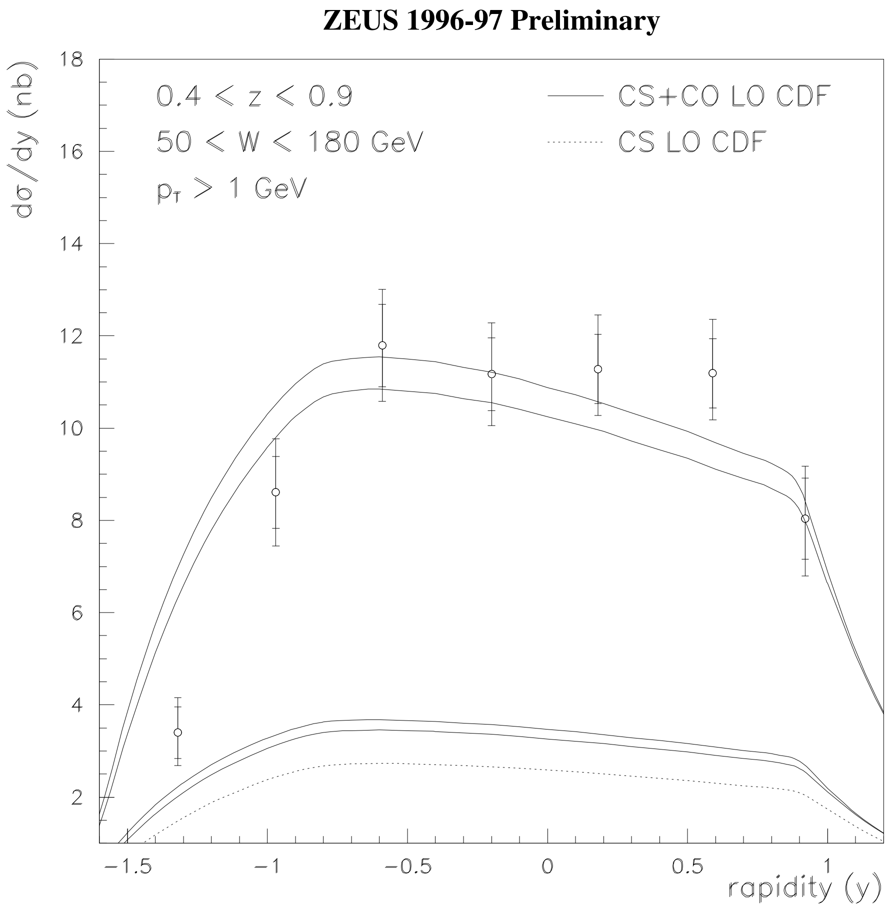
LO Colour Singlet + Octet with CDF matrix elements below data but shape roughly agrees. (Need K factor of about 3.)

NLO direct Colour Singlet roughly agrees with data for $m_c = 1.4\,\mathrm{GeV}, 35\%$ lower for $m_c = 1.55\,\mathrm{GeV}$

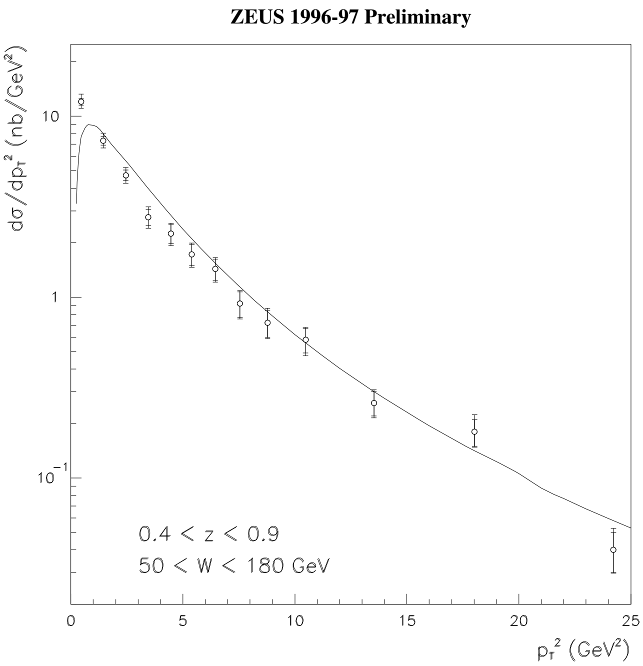
For $p_\perp > 2\,\mathrm{GeV}$:

LO Colour Singlet + Octet with CLEO matrix elements agrees with data at high z,below at low z

INELASTIC J/ψ



LO Colour Singlet + Octet with CDF matrix elements below data (Need K factor of about 3), Also shape disagreement for negative rapidity.



For $p_\perp > 1\,\mathrm{GeV}$

NLO direct Colour Singlet describes data in $p_\perp^2$

CONCLUSIONS

$D_s \to \phi\pi$

- **Differential cross sections above fixed order NLO prediction as for D^* photoproduction in same kinematic range.**

- **Results tend to support universal charm fragmentation**

Excited Charm Mesons

- **Evidence for $D_1^0, D_2^{*0} \to D^{*\pm}\pi^{\mp}$ in ep collisions**

- **To fit data need interference or another narrow resonance near $2400\,\mathrm{MeV}$**

- **First estimate of $f(c \to D_1^0)$ and $f(c \to D_2^{*0})$ at HERA; Roughly consistent with e^+e^- results**

- **No $D^{*'}$ seen: $R_{D^{*'+} \to D^{*+}\pi^+\pi^-/D^{*+}} < 2.3\%$ $(95\%\ C.L.)$**

Inelastic J/ψ

- **NLO direct Colour Singlet agrees roughly with data**

- **No need for Colour Octet in measured kinematic range**