Measurement of Excited Charm and Charm-Strange mesons at HERA

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on behalf of the
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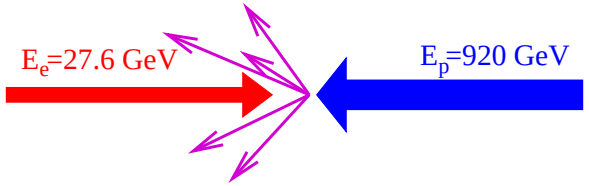
Deep Inelastic scattering Conference, 2008
LONDON

7-11 April , 2008

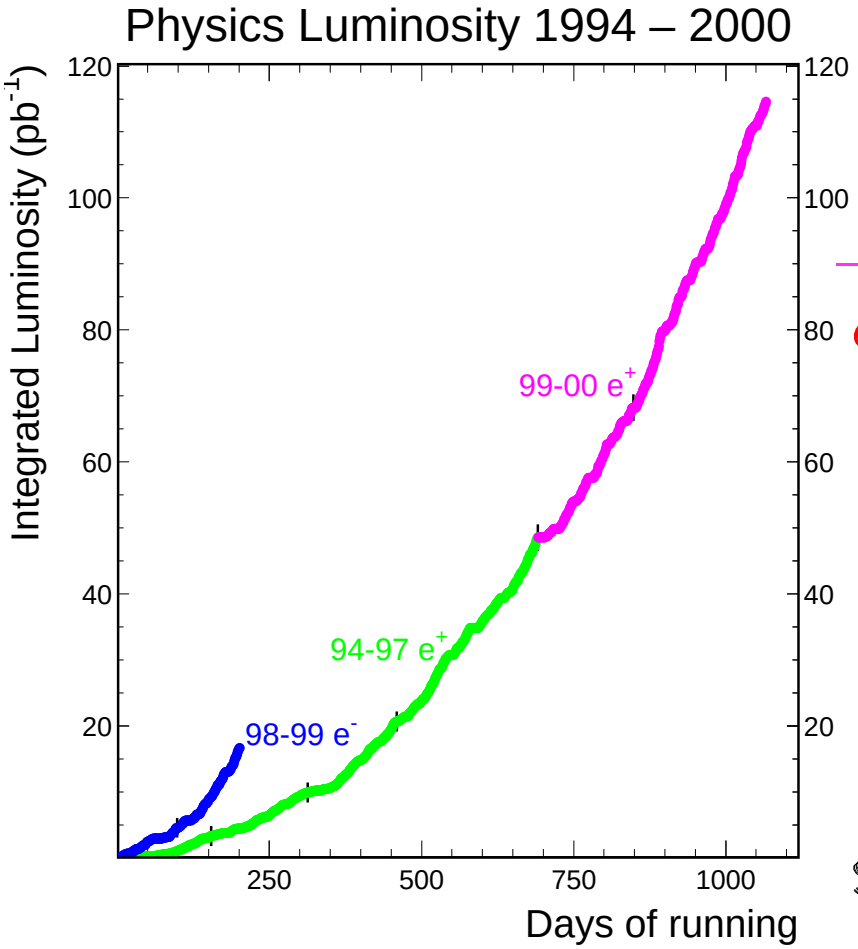
O U T L I N E

- Introduction
- Excited Charm Mesons
- Production of $D_1^0 \to D^{*\pm}\pi^{\mp}, D_2^{*0} \to D^{*\pm}\pi^{\mp}, D^{\pm}\pi^{\mp}$
- Production of $D_{s1}^{\pm} \to D^{*\pm}K_s^0, D^{*0}K^{\pm}$
- Search For $D^{*\prime\pm} \to D^{*\pm}\pi\pi$ at $\sim 2.64 GeV$
- Summary

Introduction : The HERA e - P collider , Kinematics



	HERA I	HERA II
	1992-2000	2003-2007
$\sqrt{s}$	318 **(300)**	318 **GeV**
$\mathcal{L}$	$1.5 \cdot 10^{31}$	$7 \cdot 10^{31}\, cm^{-2}\, s^{-1}$
$\mathcal{L}_{int}$	~ 0.12	$\sim 0.4\, fb^{-1}$



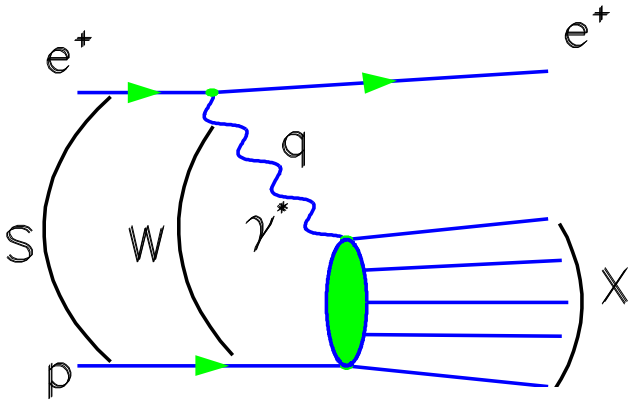
ZEUS Luminosity : $126\,\mathbf{pb}^{-1}$

$e(k) + p(P) \rightarrow e(k') + X$ $\quad s = (P+k)^2$

$$Q^2 = -q^2 = -(k-k')^2$$

Photoproduction $Q^2 \simeq 0\, GeV^2$

DIS $Q^2 > 1,5\, GeV^2$



$$W^2 = (P+q)^2$$

$$y = \frac{qP}{kP} \cong \frac{W^2+Q^2}{s}$$

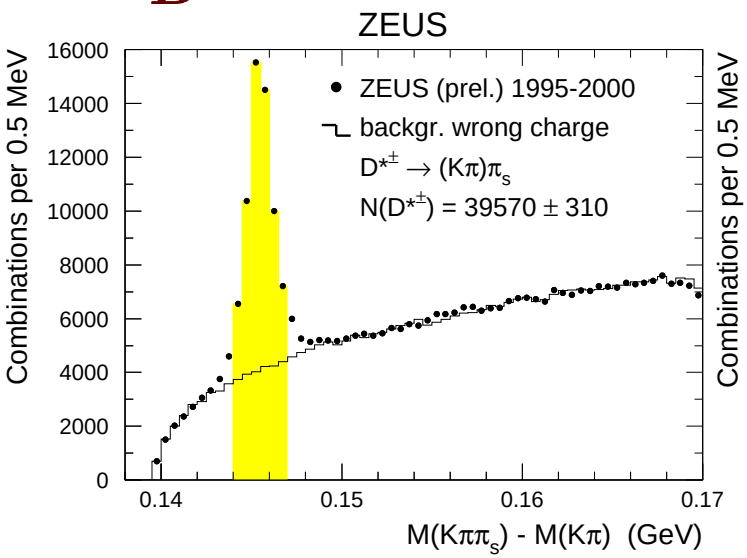
$$x = \frac{Q^2}{2qP} \cong \frac{Q^2}{sy}$$

The Ground Charm States Studied before

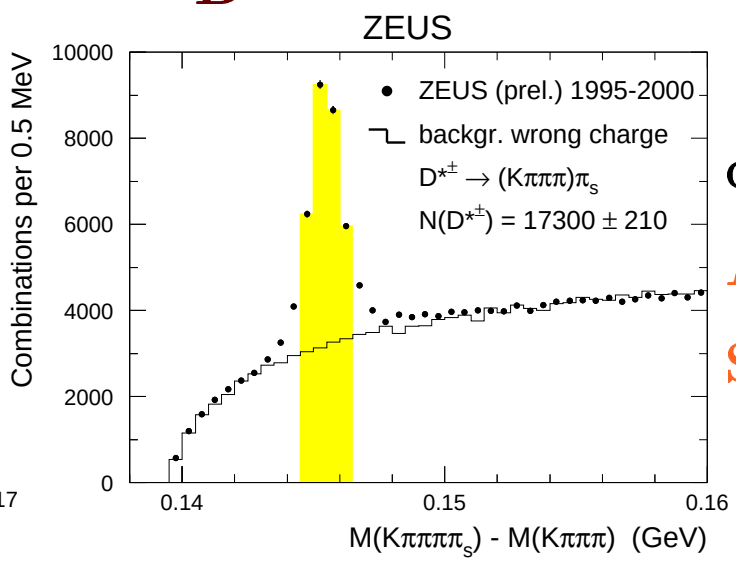
$\mathcal{L}_{int}$: 126pb^{-1} 1995-2000 Full phase space; DIS + γp events

Decays : $D^{*+} \to D^0\pi^+, D^0 \to K^-\pi^+, K^-\pi^+\pi^+\pi^- + cc$

$D^{*\pm}$



$D^{*\pm}$

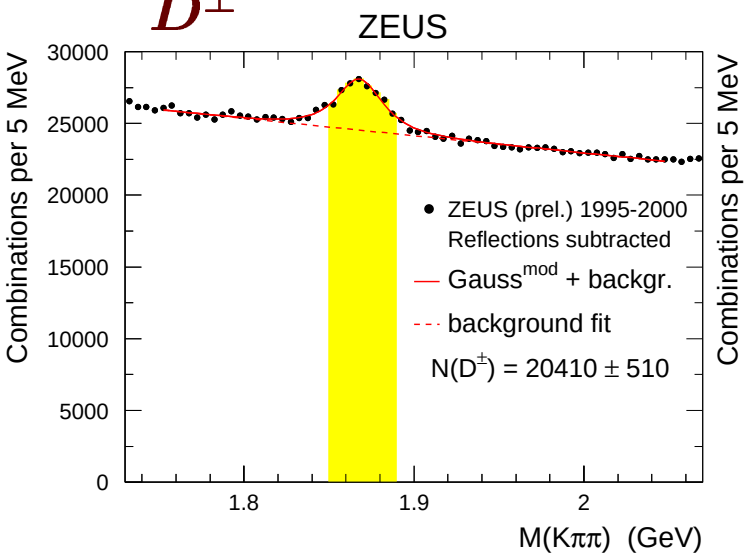


Ground states : Eur.Phys.J.C 44 (2005)35

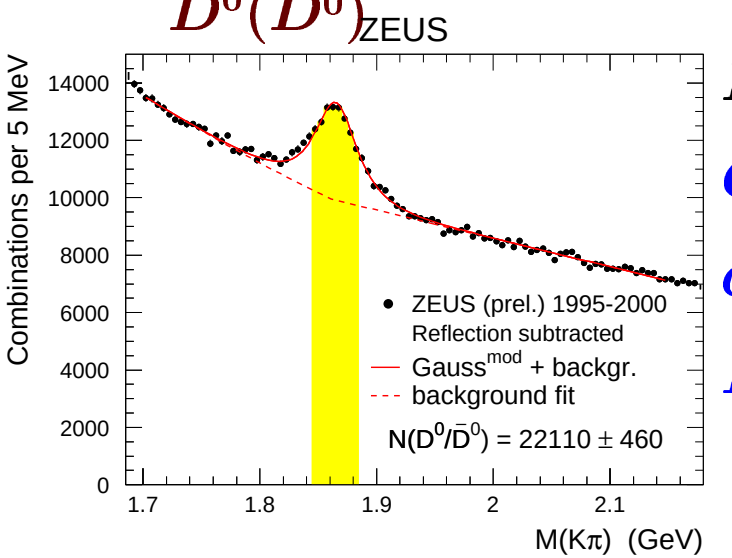
$N(D^{*\pm})$ from

Signal-Wrong Charge Bkgd

$D^{\pm}$



$D^0(\overline{D^0})$



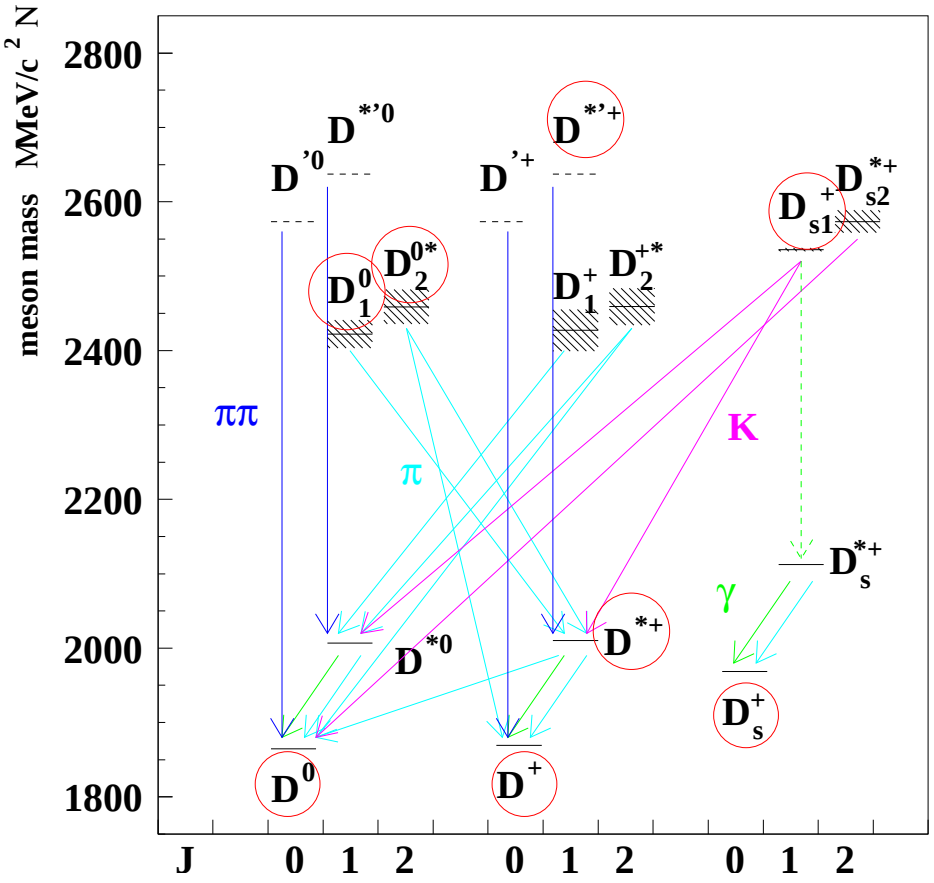
$N(D^0), N(D^{\pm})$ from fit to

$Gauss^{mod}$ + Bkgd

$Gauss^{mod} \sim exp(-0.5x^{1+\frac{1}{(1+0.5x)}})$

D^0 NOT from $D^{*\pm}$ decays

Excited Charm Mesons States Diagram and Study plan



Study : $D_1^0, D_2^{*0} \to D^{*\pm}\pi^{\mp}, D_2^{*0} \to D^{\pm}\pi^{\mp}$

$D_{s1}^{\pm} \to D^{*\pm}K_s^0, D^{*0}K^{\pm}$

Aim: Measure Excited Charm Rates:

$f(c \to D_1^0), f(c \to D_2^{*0}), f(c \to D_{s1}^{\pm})$

And Branching Fractions:

$\frac{B(D_2^{*0}\to D^+\pi^-)}{B(D_2^{*0}\to D^{*+}\pi^-)}, \frac{B(D_{s1}^+\to D^{*0}K^+)}{B(D_{s1}^+\to D^{*+}K^0)}$

Using $f(c \to D^{*\pm}), f(c \to D^{\pm}), f(c \to D^0)$

And Excited Charm Rates will yield Ratios:

$R(\frac{D_1^0\to D^{*+}\pi^-}{D^{*+}}), R(\frac{D_2^{*0}\to D^{*+}\pi^-}{D^{*+}}), R(\frac{D_2^{*0}\to D^{+}\pi^-}{D^{+}}), R(\frac{D_{s1}^+\to D^{*+}K^0}{D^{*+}}), R(\frac{D_{s1}^+\to D^{*0}K^+}{D^0})$

In Heavy Quark Effective Theory(HQET): The Helicity parameter,H is

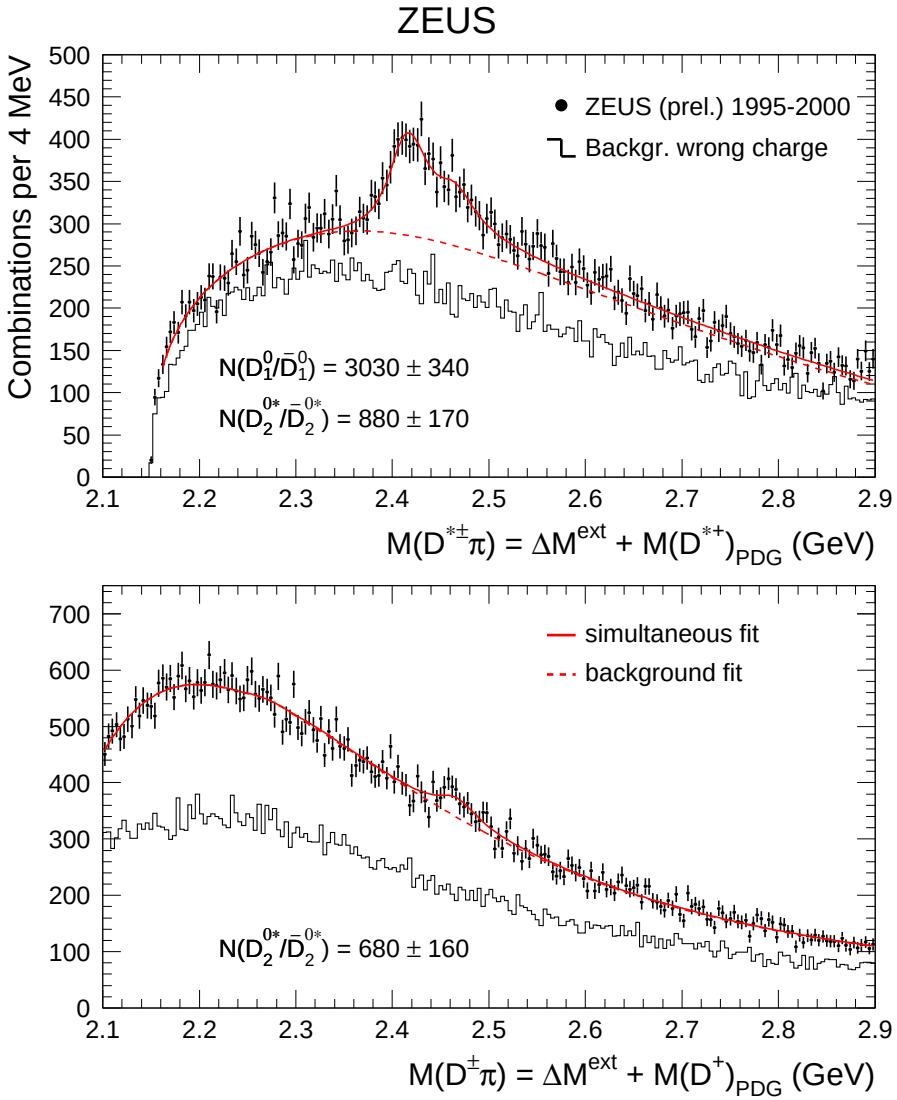
$\frac{dN}{dcos\theta} \sim 1 + Hcos^2\alpha$, $H = 3(-1)$ for $J^P = 1^+(2^+)$ from $j = 3/2$ doublet

α : Angle in $D^{*\pm}$ rest frame between extra $\pi^{\mp}(K_s^0)$ and π_s $(D^{*\pm} \to D^0\pi_s)$

Aim : Compared to e^+e^- Experiments-look for Charm Decay Universality

ZEUS(Prelim.) Excited Charm Mesons

Combine charged $D^*(D)$ with π of opposite charge,π_e



$$\Delta M^{ext} = M(K\pi\pi_s\pi_e) - M(K\pi\pi_s)$$

$$p_t(D^{*\pm}) > 1.35GeV,\ |\eta(D^{*\pm})| < 1.6$$

$$\Delta M^{ext} = M(K\pi\pi\pi\pi_s\pi_e) - M(K\pi\pi\pi\pi_s)$$

Select:$p_t(D^{*\pm}) > 2.80GeV,\ |\eta(D^{*\pm})| < 1.6$

In Plots : sum of $K\pi$ and $K\pi\pi\pi$ D^0 decays

15 parameter fit χ^2/df ,= 0.99

Difficult to separate D_1^0 from D_2^{*0}

$$\Delta M^{ext} = M(K\pi\pi\pi_e) - M(K\pi\pi)$$

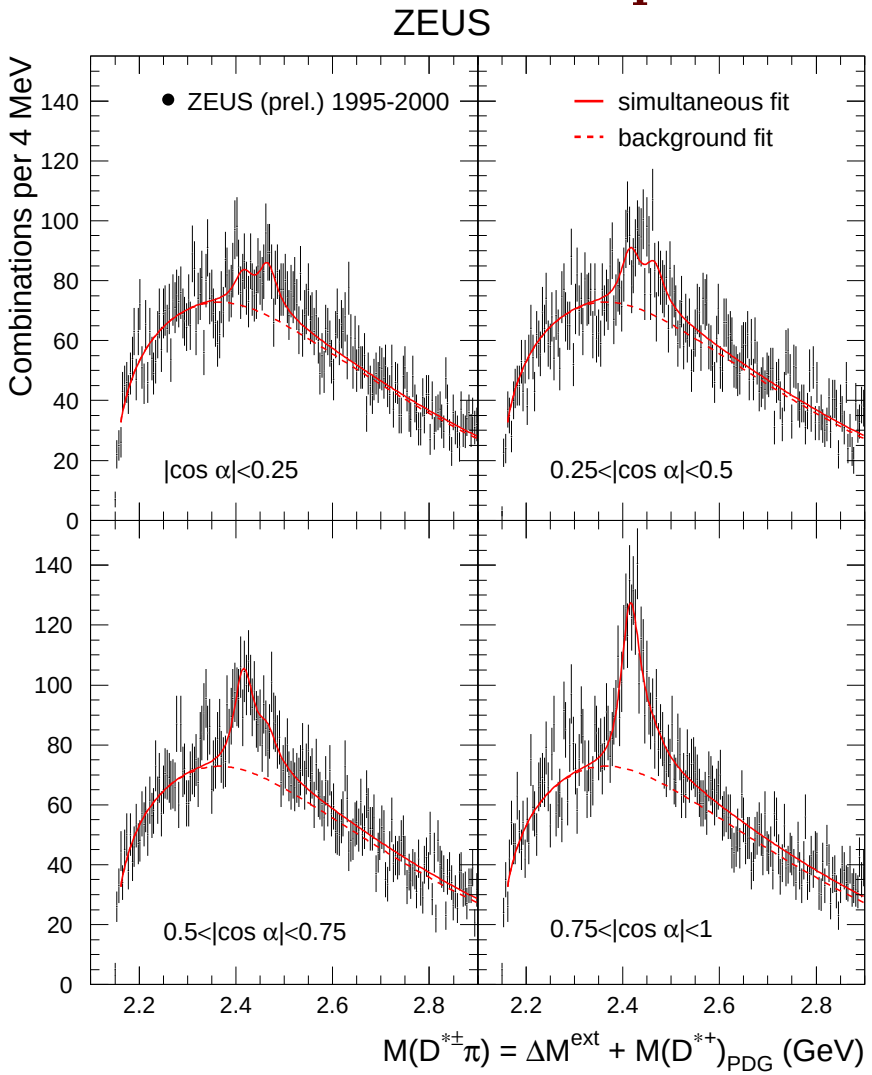
Cuts : $p_t(D^{\pm}) > 2.80GeV,\ |\eta(D^{\pm})| < 1.6$

By Spin-Parity:$D^{\pm}\pi^{\mp}$ is only from D_2^{*0} decays

ZEUS(Prelim.) Excited Charm Mesons

Simultaneous fit to 4 helicity $M(D^{*\pm}\pi^{\mp})$ Regions and $M(D^{\pm}\pi^{\mp})$ histogram

χ^2 (15 param.)fit to variable width relativistic Breit-Wigner function convoluted with experimental resolution + background function



In high $\cos(\alpha)$ bin almost all $D_1^0 \sim 1 + 3cos^2\alpha$

$M(D_1^0) = 2419.8 \pm 2.0^{+0.8}_{-1.0}\, MeV$ (Prel.)

$M(D_2^{*0}) = 2468.4 \pm 3.6^{+1.1}_{-1.3}\, MeV$ (Prel.)

$\Gamma(D_1^0) = 51.6 \pm 7.0^{+1.9}_{-4.1}\, MeV (20.4 \pm 1.7 PDG06)$

$\Gamma(D_2^{*0}) = 43 MeV$ (taken fixed from PDG06)

$H(D_1^0) = 5.9^{+3.0}_{-1.7}(stat)^{+1.9}_{-0.8}(syst)$

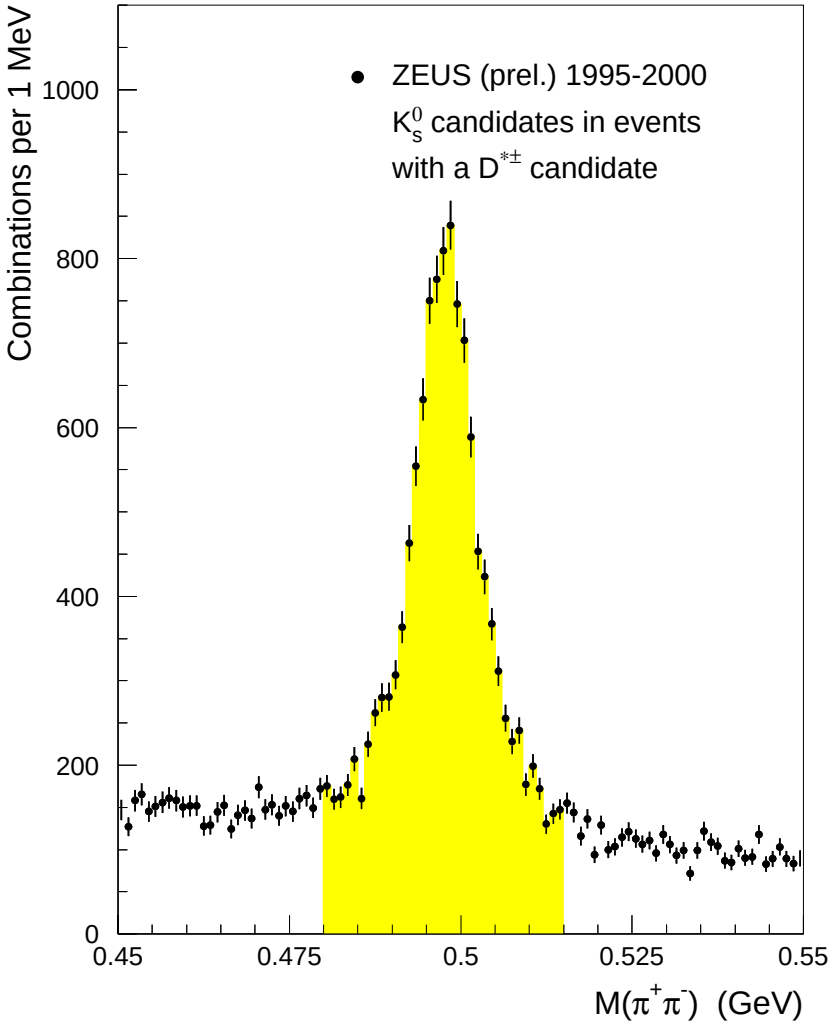
$H(D_2^{*0}) = -1$ Fixed in Fit ($J^P = 2^+$ pure state)

$R(\frac{D_1^0 \to D^{*+}\pi^-}{D^{*+}}), R(\frac{D_2^{*0} \to D^{*+}\pi^-}{D^{*+}}), R(\frac{D_2^{*0} \to D^{+}\pi^-}{D^{+}})$

Extrapolated to full kinematic phase space yields:

$\frac{B(D_2^{*0} \to D^+\pi^-)}{B(D_2^{*0} \to D^{*+}\pi^-)} = 2.7 \pm 0.8(stat.) \pm 0.6(syst.) \pm 0.1(ext.)$ 2.3 ± 0.6 (PDG06)

Excited Charm Strange Mesons : $D_{s1}^{\pm} \to D^{*\pm} K_s^0, D^{*0} K^{\pm}$



Selection of K_s^0 candidates :

For both its pions $p_t(\pi) > 0.15 GeV$

Fit to $Gauss^{mod}$ + Linear Bkgd yielded

$M(K_s^0) = 497.8 \pm 0.1$,$\sigma(K_s^0) = 4.1 \pm 0.1$ Mev

In selected region : $0.480 < M(K_s^0) < 0.515 GeV$

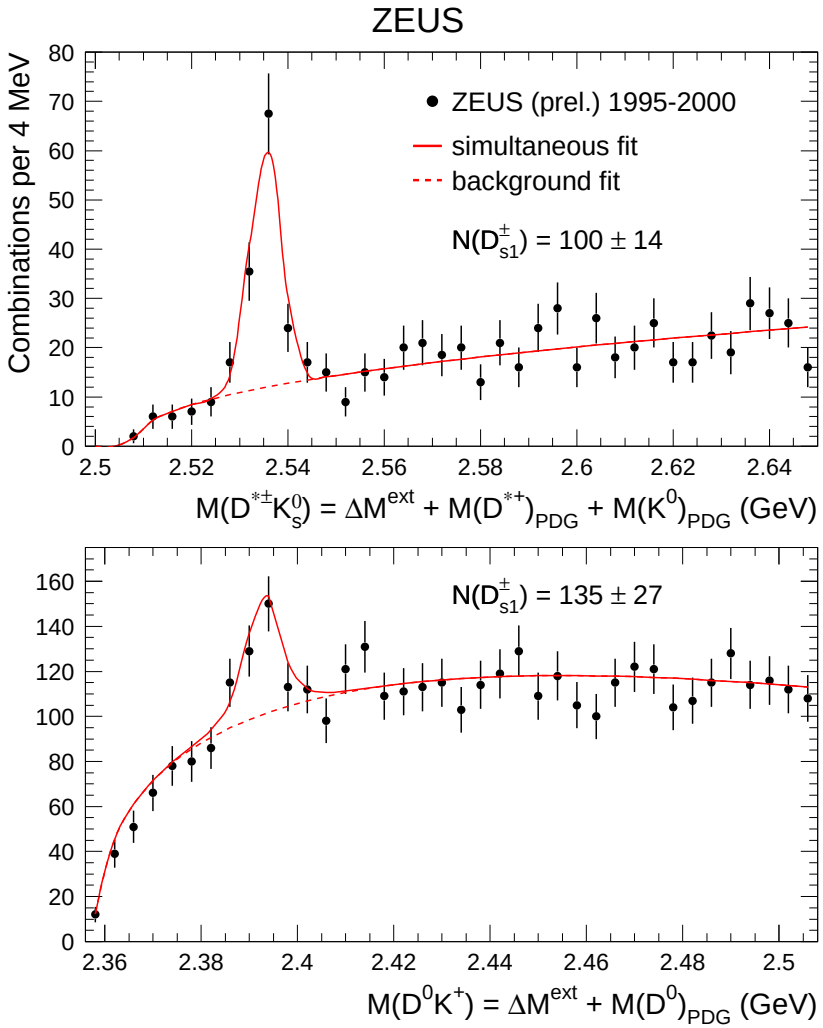
8540 ± 120 events were found

$\frac{dE}{dx}$ selection was used for $K^{\pm}, \pi$

ZEUS(Prelim.) Excited Charm Strange Mesons

Simultaneous fit of $M(D^{*\pm}K^0_s)$, $M(D^0K^\pm)$ and $cos(\alpha)$ distributions

Gaussian ($Gauss^{mod}$ for $M(D^0K^\pm)$)+ background unbinned liklihood fit



$$\Delta M^{ext} = M(K\pi\pi_s\pi^+\pi^-) - M(K\pi\pi_s)$$

$$p_t(D^{*\pm}) > 1.35GeV, \quad |\eta(D^{*\pm})| < 1.6$$

$$\Delta M^{ext} = M(K\pi\pi\pi\pi_s\pi^+\pi^-) - M(K\pi\pi\pi\pi_s)$$

$$p_t(D^{*\pm}) > 2.80GeV, \quad |\eta(D^{*\pm})| < 1.6$$

Plot contains sum of $K\pi$ and $K\pi\pi\pi$ $D^{*\pm}$ decays

$$M(D_{s1}) = 2535.3^{+0.44}_{-0.41}(stat.)^{+0.09}_{-0.08}(syst.)\ MeV$$

$$H(D_{s1}) = -0.74^{+0.23}_{-0.17}(stat.)^{+0.06}_{-0.05}(syst.) \quad \text{(Prel.)}$$

$$\Delta M^{ext} = M(K\pi K^\pm) - M(K\pi)$$

$$p_t(D^0) > 2.80GeV, \quad |\eta(D^0)| < 1.6$$

$$R(\frac{D^+_{s1}\to D^{*+}K^0}{D^{*+}}), \quad R(\frac{D^+_{s1}\to D^{*0}K^+}{D^0})$$

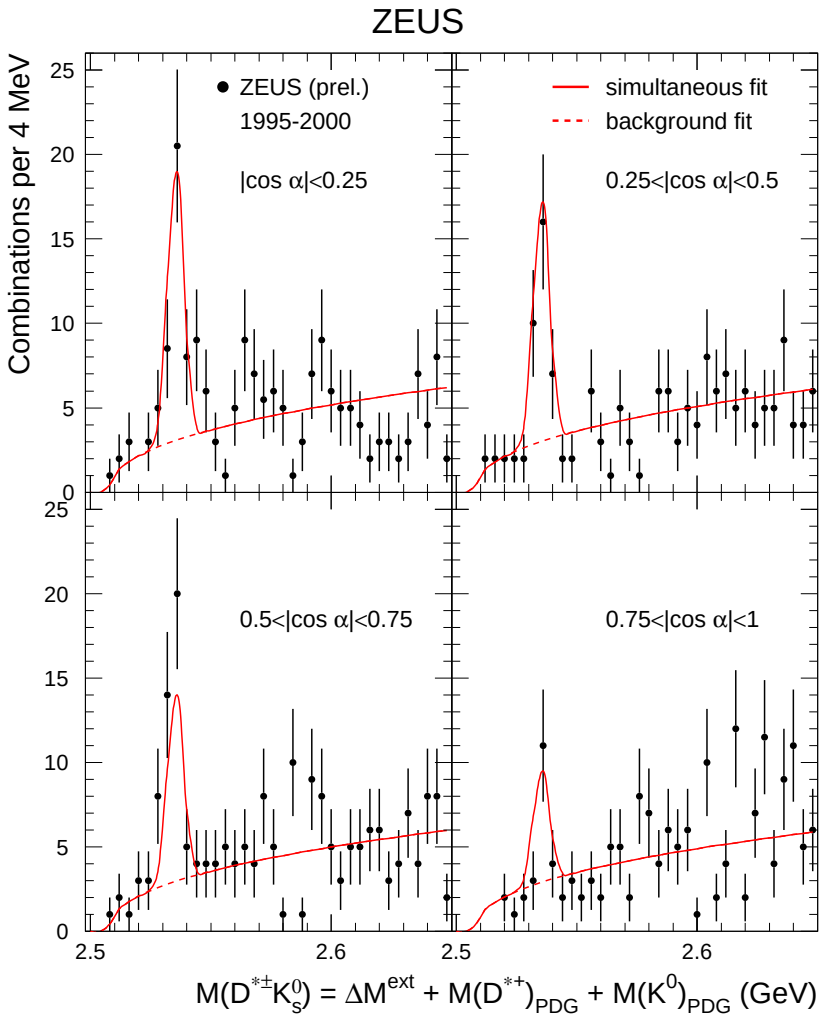
Extrapolated to full kinematic phase space yields:

$$\frac{B(D^+_{s1}\to D^{*0}K^+)}{B(D^+_{s1}\to D^{*+}K^0)} = 2.2 \pm 0.6(stat.)^{+0.4}_{-0.5}(syst.) \pm 0.1(ext.) \quad 1.27 \pm 0.21 \text{ (PDG06)}$$

Excited Charm Strange Mesons 4 Helicity regions

Simultaneous fit of $M(D^{*\pm}K_s^0)$, $M(D^0K^\pm)$ and $cos(\alpha)$ distributions

Gaussian ($Gauss^{mod}$ for $M(D^0K^\pm)$)+ background unbinned liklihood fit



Since $\frac{dN}{dcos\theta} \sim 1 + Hcos^2\alpha$ and H for $D_{s1}^{\pm}$ is -0.74,the lower right bin has fewer events, compared with the D_1^0 case where H is 5.9,and so this bin had the most events

Summary : Excited Charm Mesons (Prelim.)

	$f(c \to D_1^0)(\%)$	$f(c \to D_2^{*0})(\%)$	$f(c \to D_{s1}^{\pm})(\%)$
ZEUS	$3.5 \pm 0.4^{+0.4}_{-0.6} \pm 0.2$	$3.8 \pm 0.7 \pm 0.6 \pm 0.2$	$1.1 \pm 0.2 \pm 0.1$
CLEO	1.8 ± 0.3	1.9 ± 0.3	
OPAL	2.1 ± 0.8	5.2 ± 2.6	$1.6 \pm 0.4 \pm 0.3$
ALEPH			$0.94 \pm 0.22 \pm 0.07$

CLEO measured smaller resonance widths,OPAL used PDG values

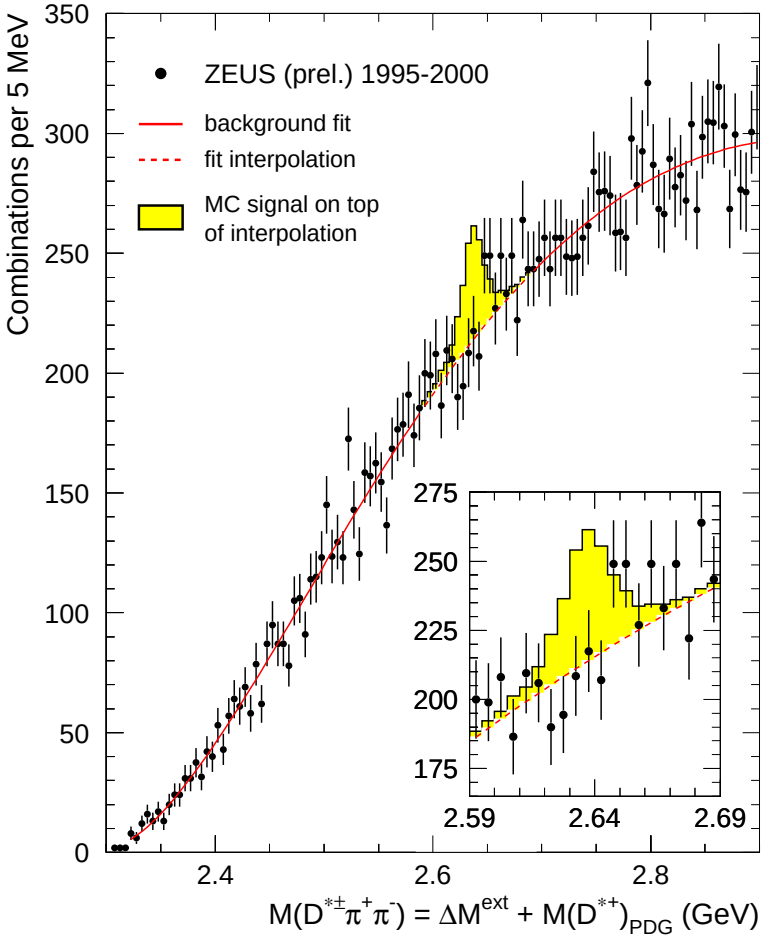
CLEO and OPAL used non relativistic Breit Wigner functions in their fits

	Helicity Parameter, H $(D_{s1}^{\pm})$
ZEUS	$-0.74^{+0.23}_{-0.17}(stat.)^{+0.06}_{-0.05}(syst.)$ (Prel.)
CLEO	$-0.23^{+0.40}_{-0.32}$
Belle(prelim.)	-0.70 ± 0.03

$H = 0 \Rightarrow J^P = 1^+$ (if pure S wave), $H = -1 \Rightarrow J^P = 1^-$ or 2^+

Possible (S,D) wave mixing of $D_{s1}^{\pm}(2536)$ with $D_{sj}^{\pm}(2460)$ if both are $J^P = 1^+$

Search for $D^{*\prime\pm} \to D^{*\pm}\pi\pi$ at $\sim 2.64 GeV$



We searched for (radially excited) $D^{*\prime} \to D^{*}\pi\pi$ state

Reported by the Delphi Collaboration , Phys. Lett.B 426,231(1998)

No such state was seen. Our limit for

$f(c \to D^{*\prime})\mathrm{x}BR(\mathrm{D}^{*\prime\pm} \to D^{*\pm}\pi\pi)$ is $< 0.4\%(95\% cl)$

This limit is stronger than the 0.9 % OPAL limit (2001)

The inset shows the $D^{*\prime\pm}$ signal expected for the Delphi value

Summary

- **ZEUS:Measured $f(c \to D_1^0), f(c \to D_2^{*0}), f(c \to D_{s1}^{\pm})$**
  Our measured rates agree with those of other experiments
- **The D_1^0 Helicity $5.9^{+3.0}_{-1.7}$ agrees with H=3,pure d-wave$J^P = 1^+$**
- **The $D_{s1}^{\pm}$ Helicity Parameter -0.74 $^{+0.23}_{-0.17}$ disagrees with a Pure $J^P = 1^+$, S wave, $D_{s1}^{\pm}(2536)$ state , for which H = 0**
  It may be mixed with a $J^P = 1^+$ $D_{sj}^{\pm}(2460)$ state
- **We find $\Gamma(D_1^0) = 51.6 \pm 7$ MeV , compared with PDG 06 : 20.4 ± 1.7 MeV**
- **Possible explanation : a larger S-wave admixture in ZEUS with a wide resonance , not so in other restricted phase space experiments**
- **No $D^{*\prime\pm} \to D^{*\pm}\pi\pi$ at ~ 2.64 GeV was seen. New limit set**

Backup: Decay of D_1^0, D_2^{*0}

D_1^0 : unnatural parity 1^+ ; cant decay to $0^- + 0^-$ $(D^{\pm}\pi^{\mp})$

But D_1^0 CAN decay to a p-wave $D^*(1^-)$ plus $\pi(0^-)$

D_2^0 : natural parity, 2^+ so CAN decay to $0^- + 0^-$ (d orbital)

D_2^0 : also can decay to $D^*(1^-)$ plus $\pi(0^-)$, d orbital

Hence D_2^0 was searched both in $D^*\pi$ and in $D^{\pm}\pi$

Relativistic Breit-Wigner was used to describe the resonances:

$$F(m) = C_R\left(\frac{M_R\Gamma_R}{(M_R^2-m^2)^2+M_R^2\Gamma_R^2}\right)$$

Ref: J.D.Jackson, Nuov.Cim. 34,(1964) 1644

Backup: References

ZEUS Collaboration; S. Chekanov et al.

Measurement of K^0_s, Λ,$\overline{\Lambda}$ Production at HERA

European Physical Journal C 51 (2007) 1-23

ZEUS Collaboration; S. Chekanov et al.

Measurement of (anti)deuteron and (anti)proton production in DIS at HERA

DESY-07-070 (May 2007),accepted by Nuclear Physics B

ZEUS Collaboration; S. Chekanov et al.

Evidence for a narrow baryonic state decaying to $K^0_s\overline{p}$ in deep inelastic scattering at HERA

Physics Letters B 591 (2004) 7-22

ZEUS Collaboration; S. Chekanov et al.

Search for a narrow charmed baryonic state decaying to $D^{*+}\,\overline{p}$ in ep collisions at HERA

European Physical Journal C 38 (2004) 29-41

H1 Collab., A. Aktas et al., hep-ex/0704.3594, To be submitted to Phys. Lett. B ,04/07

Search for Baryonic Resonances Decaying to $\Xi\pi$ in Deep-Inelastic Scattering at HERA

H1 Collab., A. Aktas et al., Phys. Lett. B 639 (2006) 202

Search for a Narrow Baryonic Resonance Decaying to $K^0_s p$ or $K^0_s\,\overline{p}$ in Deep Inelastic Scattering at HERA

H1 Collab., A. Aktas et al., Eur. Phys. J. C36 (2004) 413-423

Measurement of Anti-Deuteron Production and a Search for Heavy Stable Charged Particles at HERA

H1 Collab., C. Adloff et al., Z. Phys. C76 (1997) 213

Photoproduction of K^0 and Λ at HERA and a Comparison with Deep Inelastic Scattering

Backup: References

CLEO Coll., P. Avery et al.,Phys. Lett. B 331, 236 (1994)

OPAL Coll., K. Ackerstaff et al.,Z. Phys. C 76, 425 (1997)

ALEPH Coll., A. Heister et al.,Phys. Lett. B 526, 34 (2002)

CLEO Coll., J.P. Alexander et al.,Phys. Lett. B 303, 337 (1993)

BELLE Coll., K. Abe et al.,(hep-ex/0507030)

CDF Coll., A. Abulencia et al.,Phys. Rev. D 75,32003 (2007)