

Charm fragmentation and excited charm and charm-strange mesons at ZEUS



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OUTLINE :

Charm Factory HERA

charm fragmentation, JHEP04 (2009) 089

QCD scaling violation for $\langle z \rangle$

fragmentation with LL MC

fragmentation with FO NLO

excited D mesons, EPJC60 (2009) 25

$D_1^0, D_2^{*0} \rightarrow D^{*+} \pi^-; D_2^{*0} \rightarrow D^+ \pi^-$

$D_{s1}^+ \rightarrow D^{*+} K_s^0, D^{*0} K^+$

search for $D^{*'+} \rightarrow D^{*+} \pi^+ \pi^-$

Summary

BACKUP :

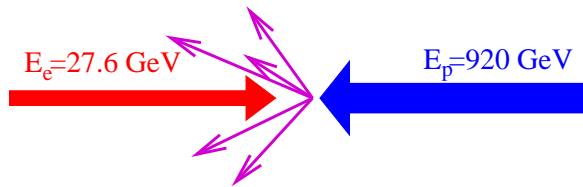
more on $D^{*\pm}, D^\pm, D^0$ reconstruction

more on D_1^0 and D_2^{*0} fit

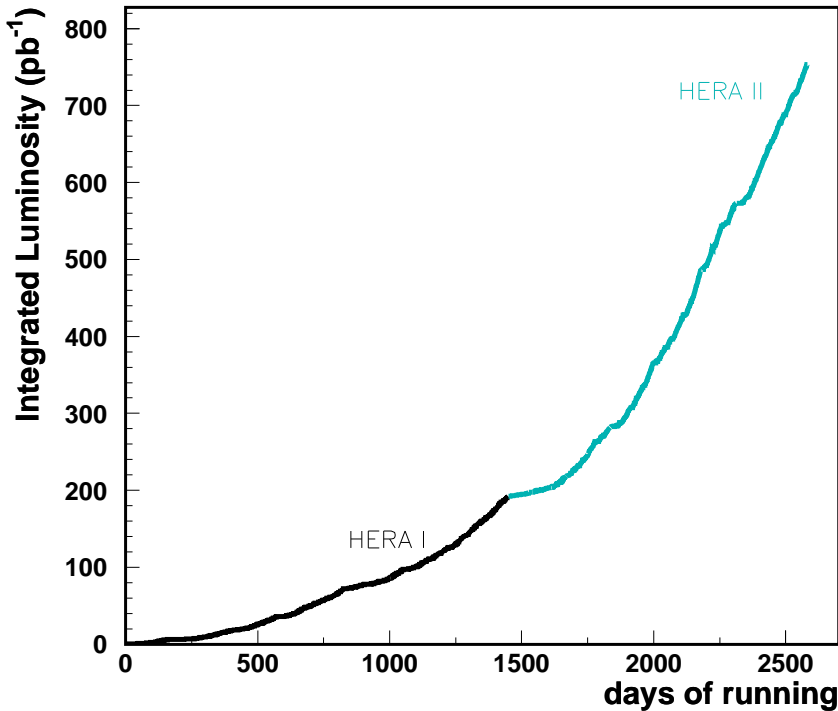
more on D_1^0 and D_2^{*0} fractions

more on D_{s1}^+ fractions

Charm Factory HERA



HERA delivered



ZEUS Collaboration

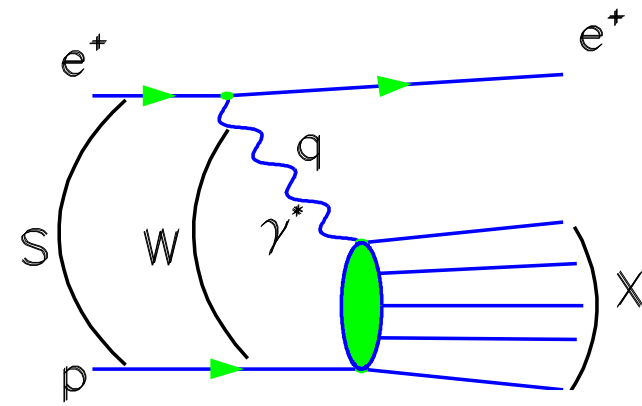
	HERA	HERA II
	1992-2000	2003-2007

\sqrt{s}	320 (300)	320 GeV
\mathcal{L}	$1.5 \cdot 10^{31}$	$7 \cdot 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$
\mathcal{L}_{int}	0.13	0.37 fb^{-1}

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

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

Photoproduction $Q^2 \simeq 0 \text{ GeV}^2$
 DIS $Q^2 > 1 \text{ GeV}^2$



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

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

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

$$\sigma_{c\bar{c}} \approx 1 \mu\text{b} \Rightarrow 10^9 \text{ events } (\mathcal{L}_{int} = 1 \text{ fb}^{-1})$$

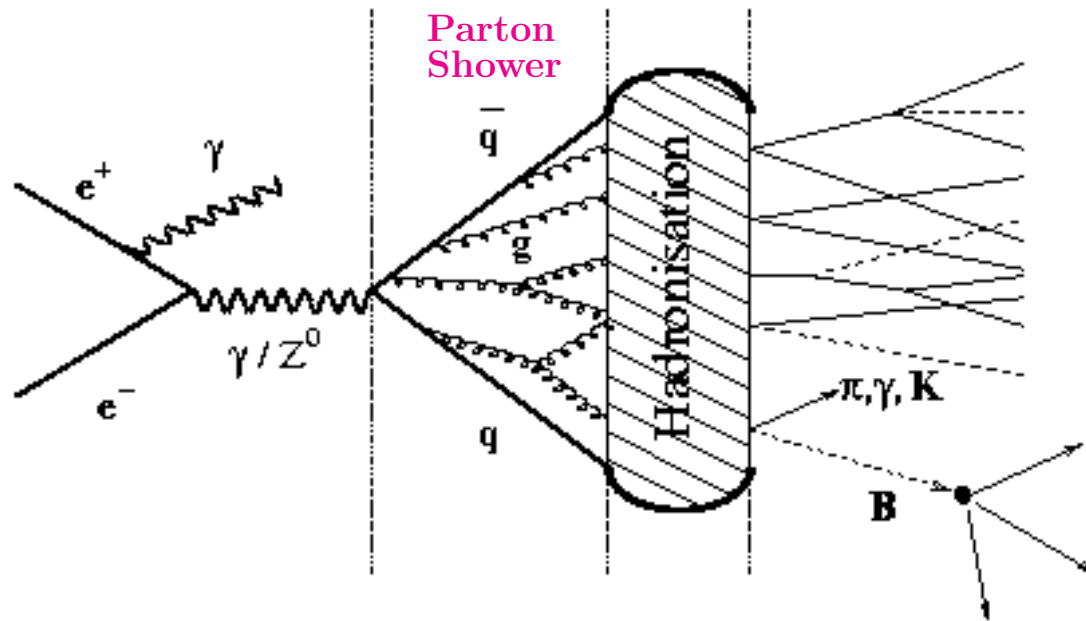
$$\sigma_{b\bar{b}} \approx 10 \text{ nb} \Rightarrow 10^7 \text{ events } (\mathcal{L}_{int} = 1 \text{ fb}^{-1})$$

Heavy Quark fragmentation

Production

Fragmentation

Decays



HQ fragmentation is hard

harder for larger m_Q

e.g., for Peterson param.:

$$f(z) \propto \frac{1}{z(1-1/z-\epsilon/(1-z))^2}$$

$$\epsilon(b) \sim \frac{m_c^2}{m_b^2} \epsilon(c) \sim 0.1 \epsilon(c)$$

pQCD is applicable to “initial” Q-fragmentation: LO, NLO, LL, NLL, ...

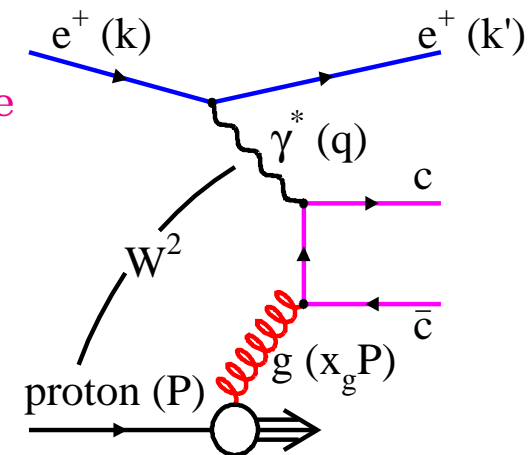
anyhow, some parameterisation is needed for the non-perturbative (NP) rest

the NP parameterisation is strongly dependent from the perturbative core and it is expected to be universal for the same perturbative core

test of universality of the NP parameterisation

is a test of generality of the particular pQCD calculation

Is the pQCD calculation with its universal NP fragmentation applic. to $Q\bar{Q}$ production at different scales and colour states ?



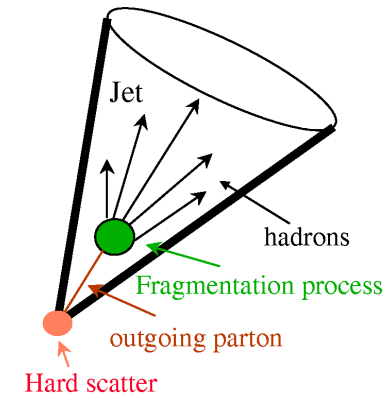
Measurement of charm fragmentation function ($D^{*\pm}$)

In e^+e^- annihilations, $D^{*\pm}$ energy is related to $\sqrt{s}/2$

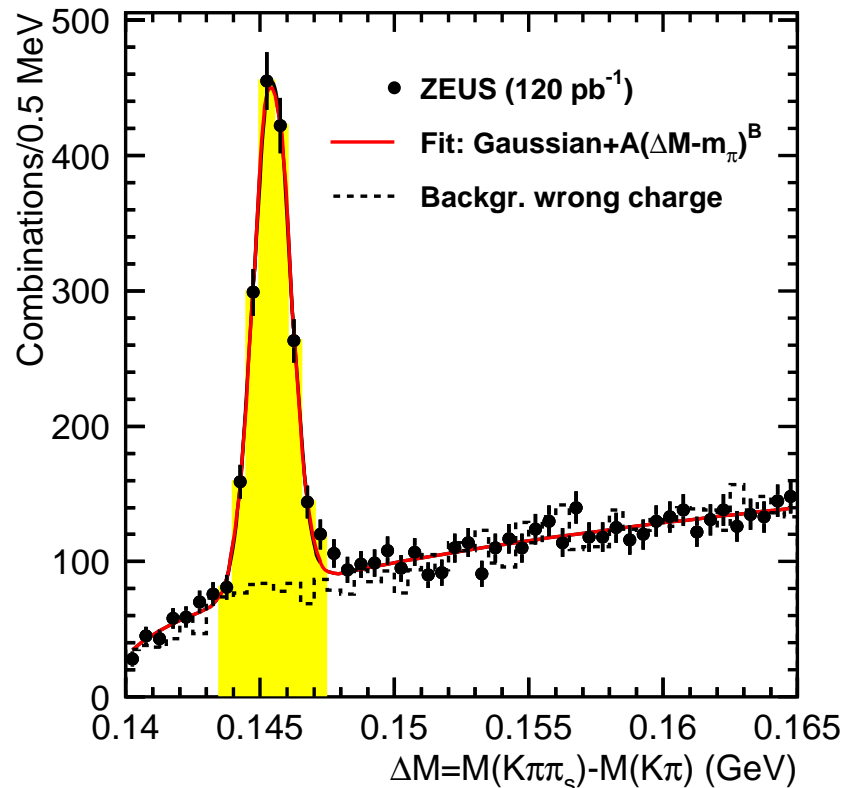
In ep collisions, find jet containing $D^{*\pm}$ and relate the $D^{*\pm}$ energy to the energy of this jet

$130 < W < 280 \text{ GeV}$, $Q^2 < 1 \text{ GeV}^2$, $P_T(D^{*\pm}) > 2 \text{ GeV}$, $|\eta(D^{*\pm})| < 1.5$

$D^{*\pm}$ belongs to a jet (k_T) with $E_T^{\text{jet}} > 9 \text{ GeV}$ and $|\eta^{\text{jet}}| < 2.4$



ZEUS



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

$$\mathcal{L}_{int} = 120 \text{ pb}^{-1}$$

$$N(D^{*\pm}) = 1307 \pm 53$$

$$z = (E + p_{||})^{D^*} / (E + p_{||})^{\text{jet}} \equiv (E + p_{||})^{D^*} / 2 E^{\text{jet}}$$

measured in range $0.16 < z < 1$

beauty contribution subtracted

correcting to $0 < z < 1$ gives

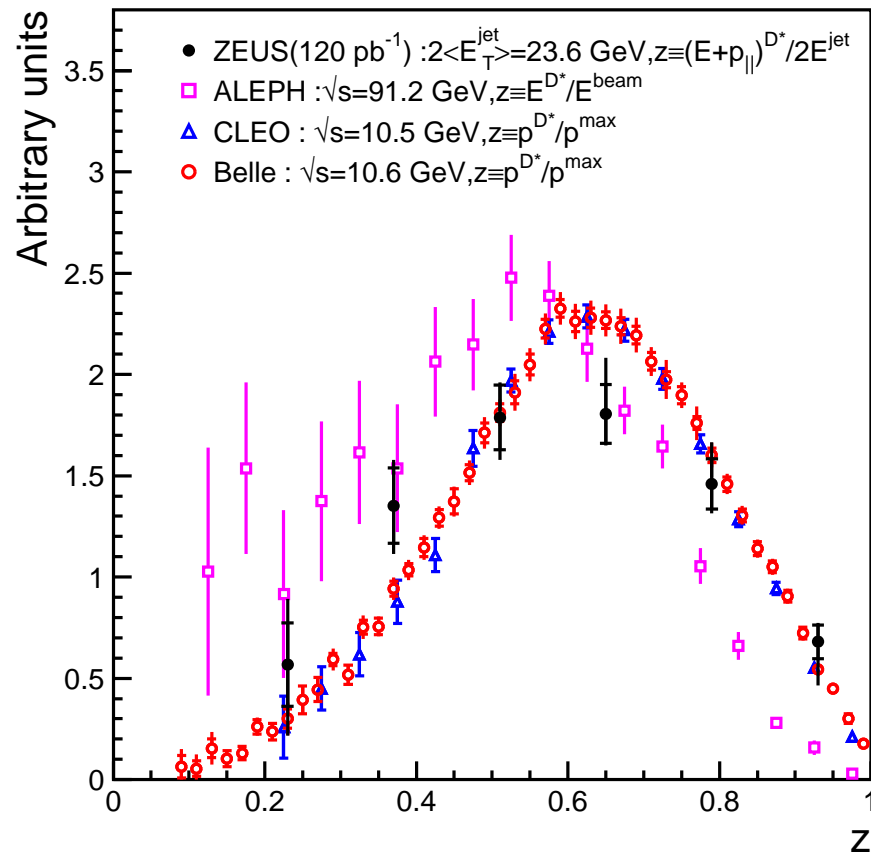
$$\langle z \rangle = 0.565 \pm 0.024 \pm 0.028$$

$$\text{at scale } \langle E_T^{\text{jet}} \rangle \times 2 = 23.6 \text{ GeV}$$

QCD scaling violation in charm fragmentation

Collaboration	Scale (GeV)	Measured variable	$\langle z \rangle \pm \text{stat.} \pm \text{syst.}$
ALEPH	91.2	$\langle E^{D^*} / E^{\text{beam}} \rangle$	$0.4878 \pm 0.0046 \pm 0.0061$
Belle	10.6	$\langle p^{D^*} / p^{\text{max}} \rangle$	$0.61217 \pm 0.00036 \pm 0.00143$
CLEO	10.5	$\langle p^{D^*} / p^{\text{max}} \rangle$	$0.611 \pm 0.007 \pm 0.004$
ZEUS	23.6	$\langle (E + p_{\parallel})^{D^*} / 2E^{\text{jet}} \rangle$	$0.565 \pm 0.024 \pm 0.028$

ZEUS



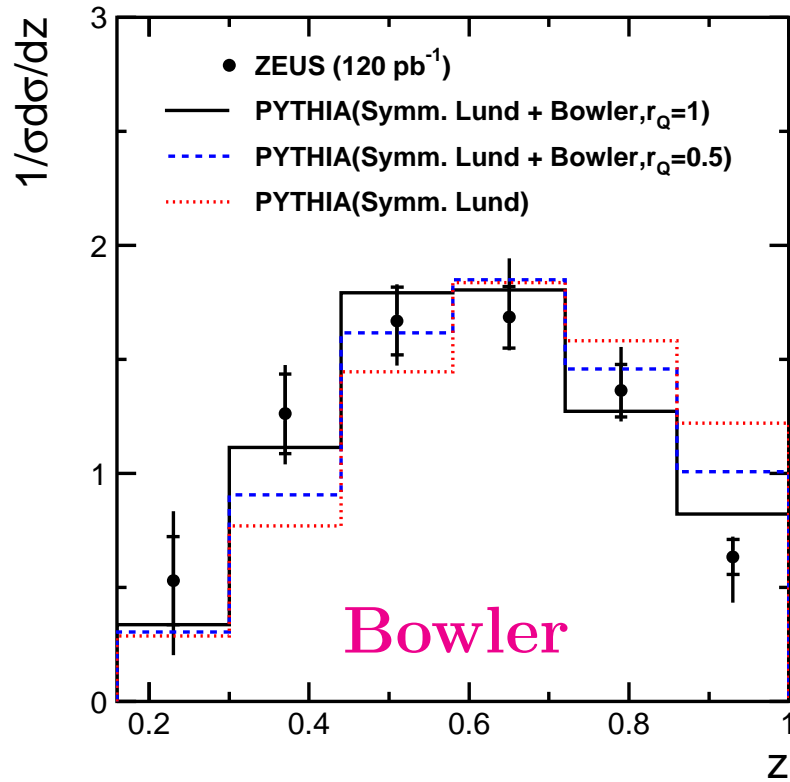
expected QCD scaling violation

larger scale \implies larger contrib.
of QCD high-order processes

pQCD calculation, if it is general,
takes care about the differences
keeping NP fragmentation universal

Charm fragmentation with leading-log. Monte Carlo

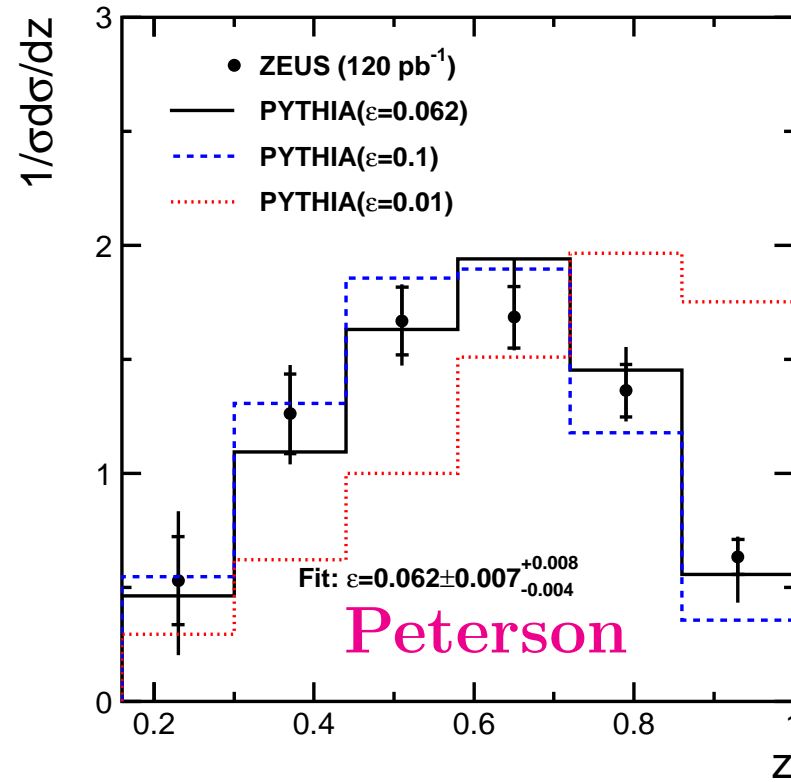
ZEUS



$$f(z) \propto \frac{1}{z^{1+r_Q b m_Q^2}} (1-z)^a \exp\left(\frac{-b m_{\perp}^2}{z}\right)$$

$r_Q = 1$ (default) is preferable

ZEUS



$$f(z) \propto \frac{1}{z(1-1/z-\epsilon/(1-z))^2}$$

$$\epsilon = 0.062 \pm 0.007^{+0.008}_{-0.004} \quad (\text{ZEUS, } \gamma p)$$

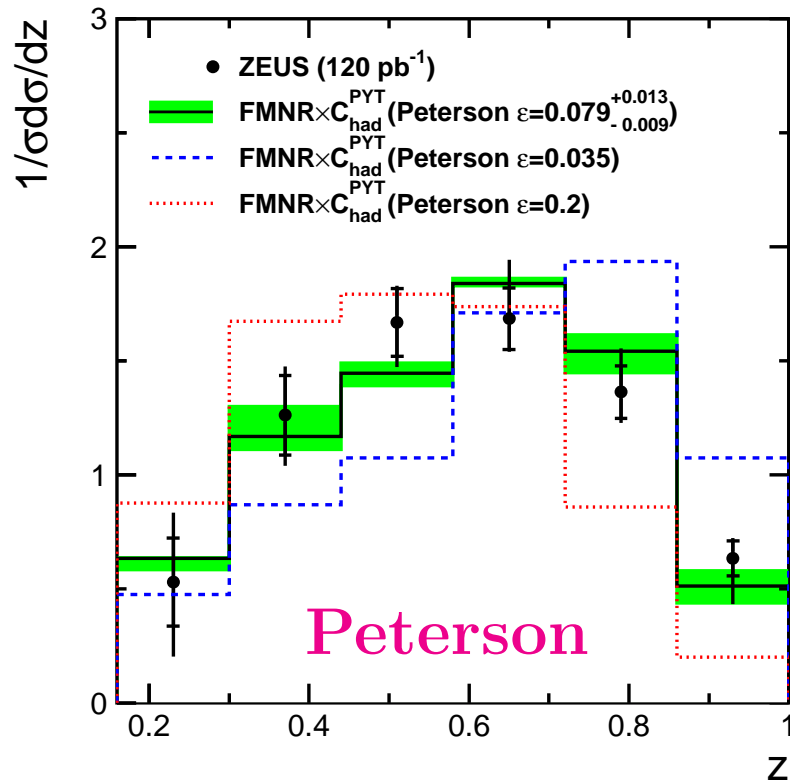
$$0.049^{+0.012}_{-0.010} / 0.061^{+0.011}_{-0.009} \quad (\text{H1, DIS, scale } \sim 10 \text{ GeV})$$

$$\epsilon = 0.05 \quad (\text{PYTHIA default})$$

$$\text{Nason, Oleari} \implies \epsilon = 0.053 \quad (\text{LL fit to ARGUS data})$$

Charm fragmentation with fixed order NLO

ZEUS



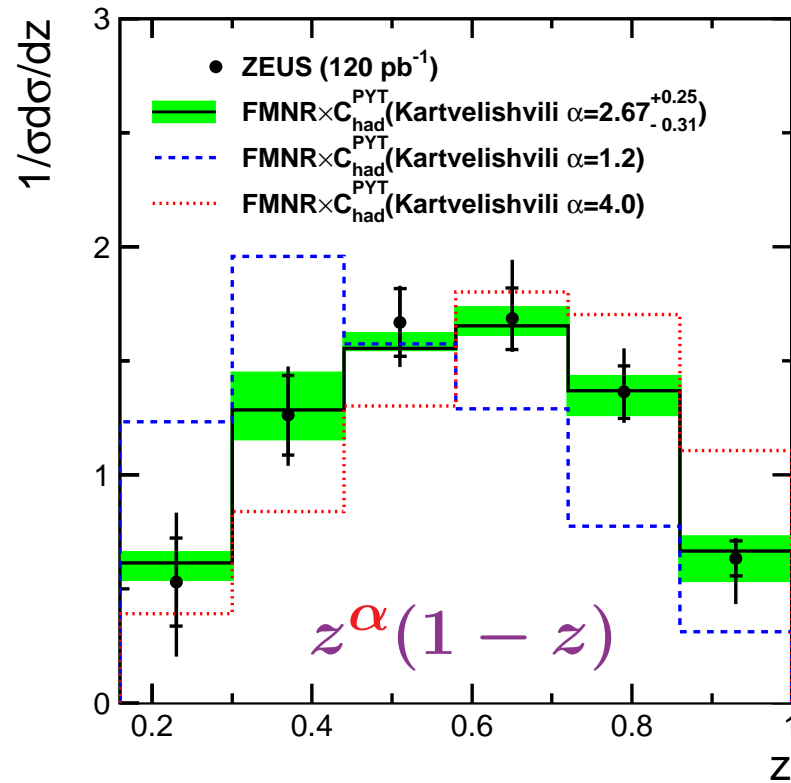
$$\epsilon = 0.079 \pm 0.008^{+0.010}_{-0.005} \text{ (ZEUS)}$$

$$0.068^{+0.015}_{-0.013} / 0.034^{+0.004}_{-0.004} \text{ (bad } \chi^2 \text{) (H1)}$$

$$\epsilon = 0.035 \text{ (NLO fit to ARGUS data)} \iff \text{Nason, Oleari}$$

$0.079 \neq 0.035 \implies$ fixed-order NLO does not provide general perturbative core factorisable from universal fragmentation

ZEUS

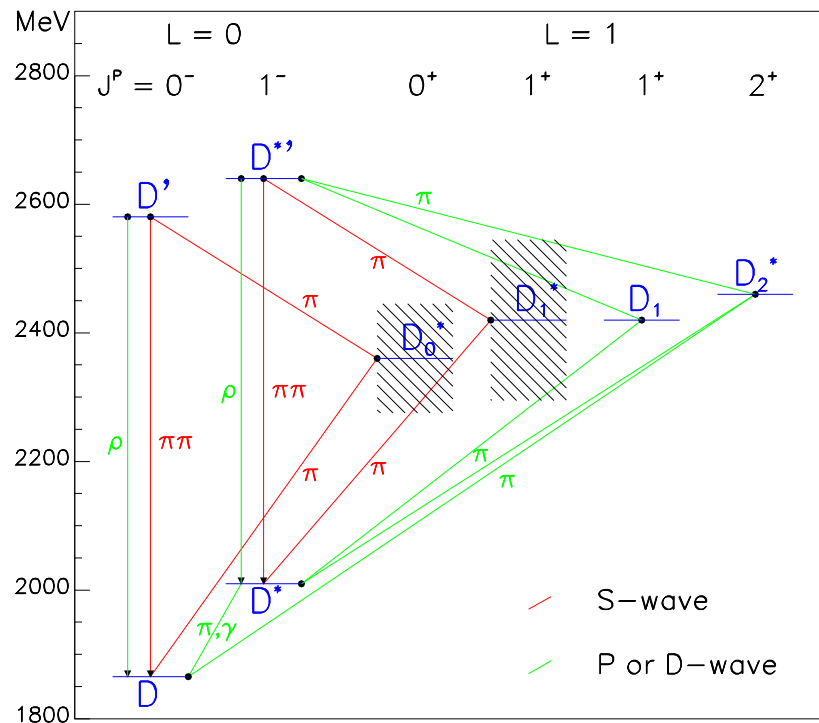


$$\alpha = 2.67 \pm 0.18^{+0.17}_{-0.25} \text{ (ZEUS, } \gamma p \text{)}$$

$$3.3 \pm 0.4 / 3.8 \pm 0.3 \text{ (H1, DIS)}$$

Excited D mesons, 20th century

Spectroscopy of D mesons



HQET predicts 2 doublets of excited D mesons ($Q\bar{q}$) with $L = 1$

doublet with $j = L + s = 3/2$,
 D -wave decays \implies narrow states

doublet with $j = L + s = 1/2$,
 S -wave decays \implies wide states

s - spin of the light quark

Radially excited ($L = 0$) D mesons are also expected

Narrow states are known since ~ 1990 (TPS, ARGUS, CLEO)

In 1999, CLEO reported wide $D_1^{*0} \rightarrow D^{*+} \pi^- (+c.c.)$ in B decays

In 1998, DELPHI reported radially excited $D^{*'}(2640)^\pm \rightarrow D^{*\pm} \pi^+ \pi^-$

Excited D mesons, 21st century

1) 2nd doublet of charm-strange mesons, $D_s(2317)$ and $D_s(2460)$, was observed by BaBar and CLEO

very narrow due to probably isospin violating decays

2) CLEO observation of wide D_1^{*0} stayed unpublished

Recently, Focus and Belle published their observations of wide D -mesons

large uncertainties in parameters and yields

3) DELPHI observation of radially excited D^{*} was not confirmed by OPAL and CLEO (prel.)

open question

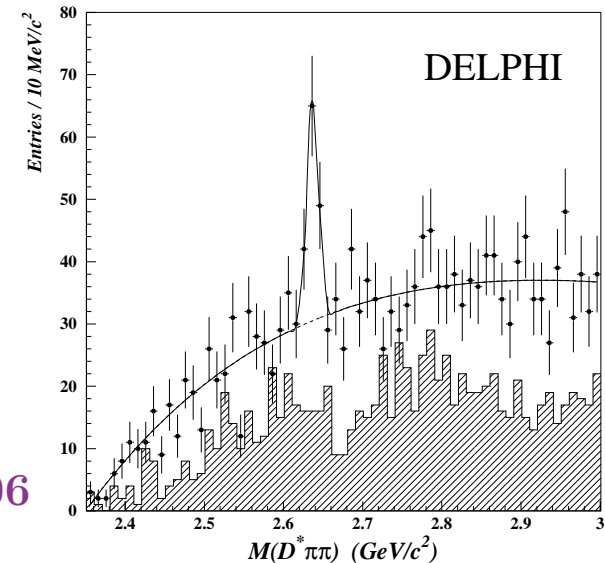
4) parameters of narrow excited D mesons are being actively re-established

e.g., $\Gamma(D_2^{*0})$ updated significantly in PDG2006

5) Fragmentation fractions, $f(c \rightarrow D_1^0)$, $f(c \rightarrow D_2^{*0})$, $f(c \rightarrow D_{s1}^+)$ and others, are purely known

contribute 20 – 30% of D/D^* production

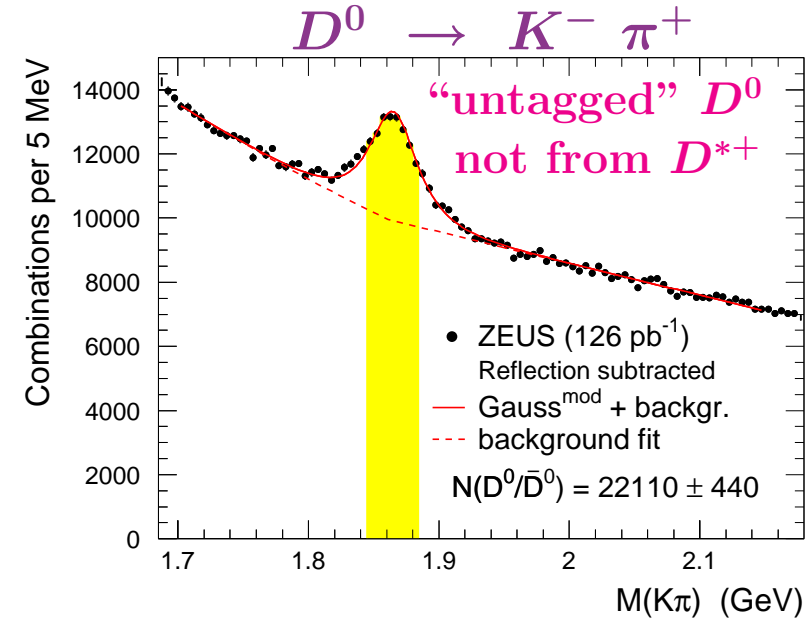
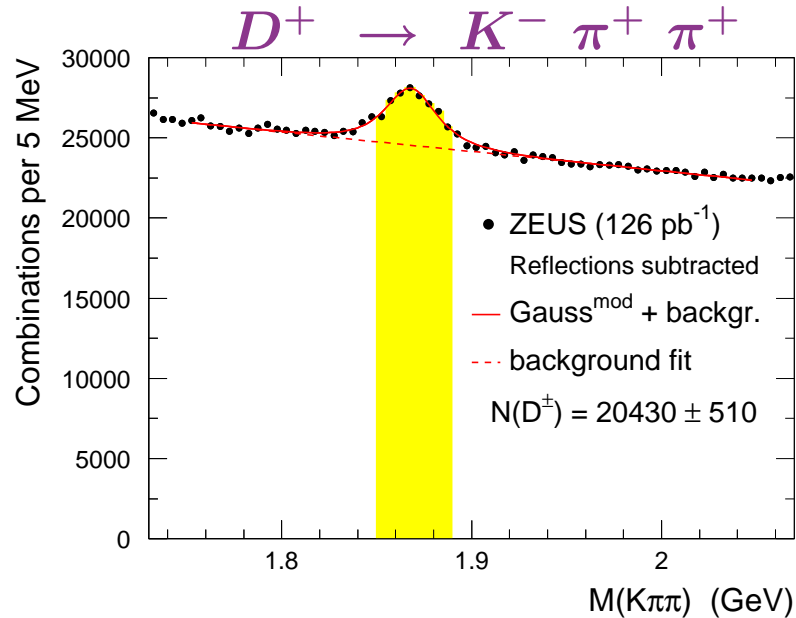
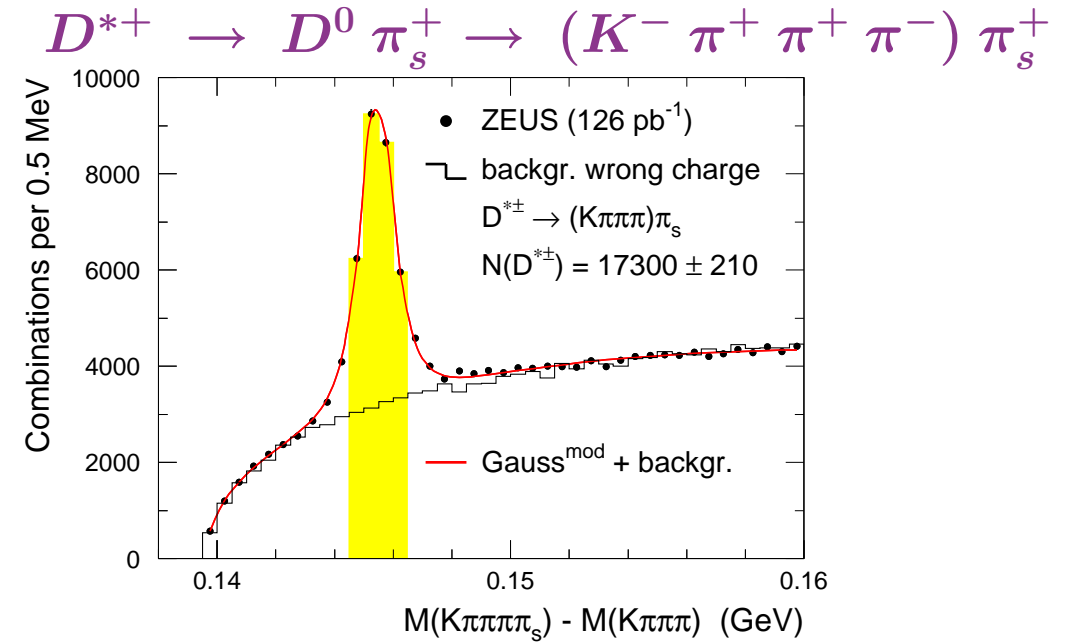
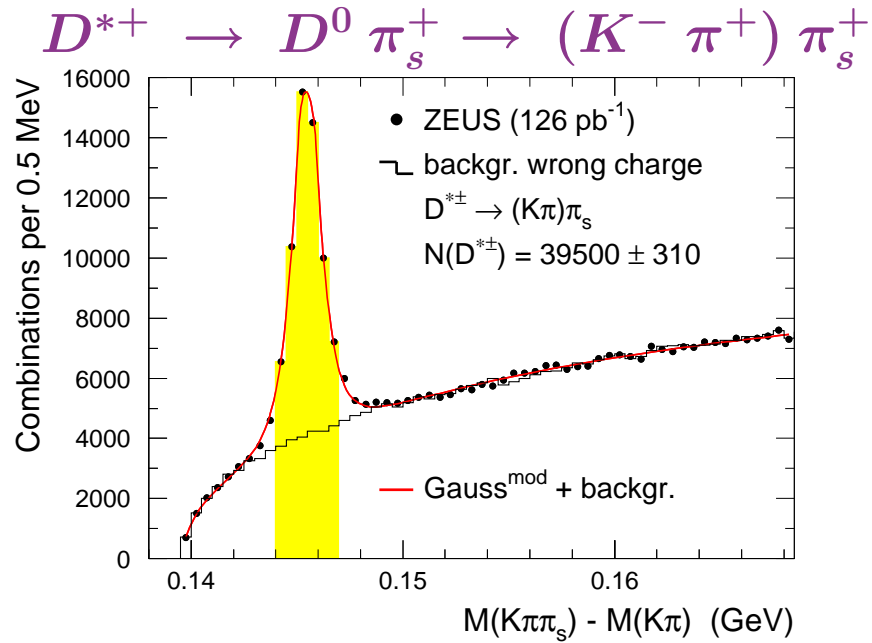
set by default to zero (!) in Lund MC generators



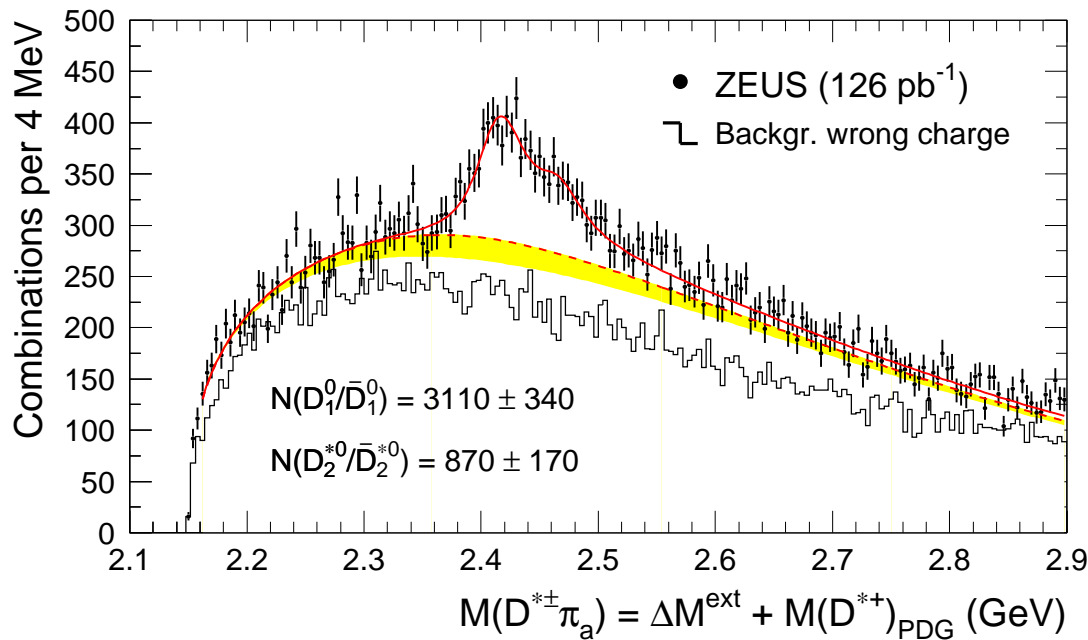
hot topic for hadron spectroscopy and for technick of perturbative QCD tests

$D^{*\pm}, D^\pm$ and D^0 reconstruction

95-00 data (126 pb^{-1}) full Q^2 range (DIS and PhP together)



$M(D^{*\pm}\pi)$ and $M(D^\pm\pi)$ distributions



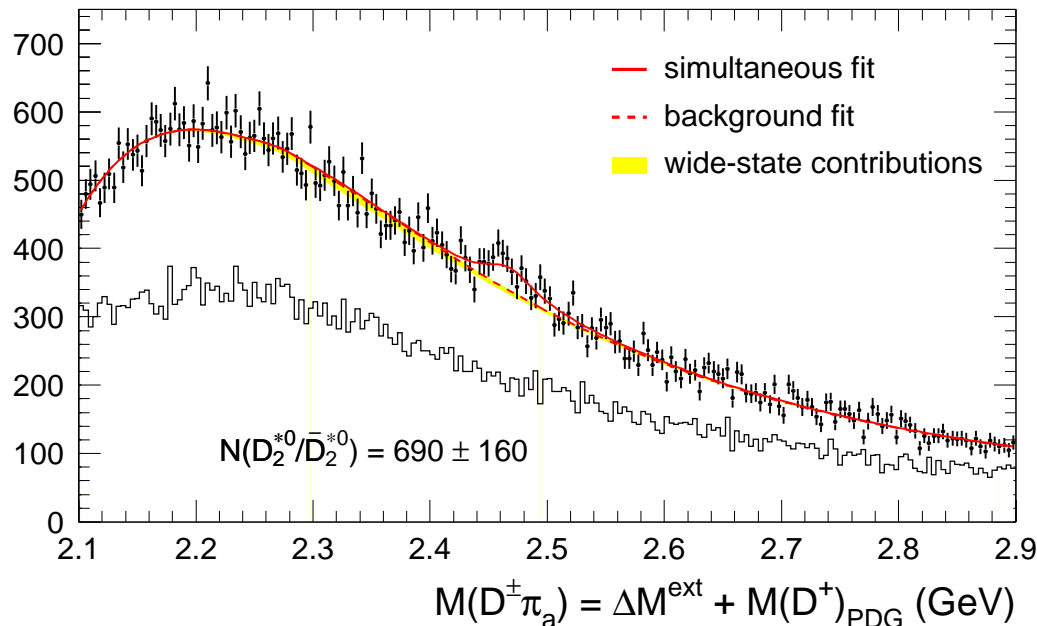
$$\Delta M^{\text{ext}} = M(K\pi\pi_s\pi_a) - M(K\pi\pi_s) \text{ or}$$

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

Clear access in the range
 $2.4 < M(D^{*+}\pi_a) < 2.5$ GeV

no access in wrong-charge distr.

wide $D_1(2430)^0$ is not distinguishable



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

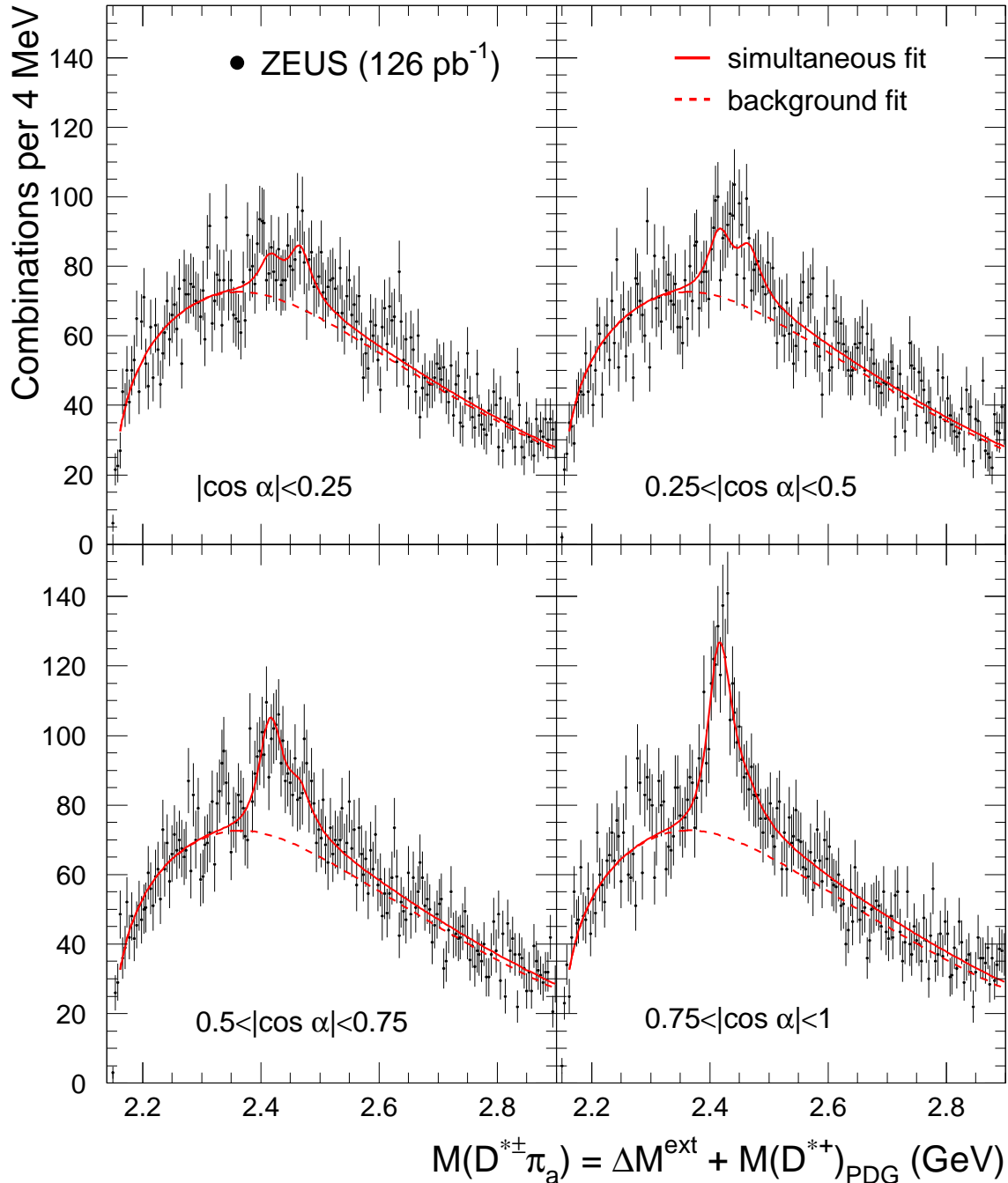
small access around 2460 MeV

no access in wrong-charge distr.

feed-downs from $D_1^0, D_2^{*0} \rightarrow D^{*+}\pi^-$
 with $D^{*+} \rightarrow D^+\pi^0/\gamma$ under background

wide $D_0(2400)^0$ and feed-down from
 $D_1(2430)^0$ are not distinguishable

$M(D^{*\pm}\pi)$ in 4 helicity intervals



helicity angle α - between π_s and π_a in $D^{*\pm}$ rest frame

$$\frac{dN}{d\cos\alpha} \propto 1 + h \cdot \cos^2\alpha, \quad h ?$$

HQET predicts:

$$h = 3 \quad \text{for } D_1^0 \quad (1^+, L + s = 3/2)$$

$$h = -1 \quad \text{for } D_2^{*0} \quad (2^+, L + s = 3/2)$$

$$h = 0 \quad \text{for } D_1^0 \quad (1^+, L + s = 1/2) \quad (\text{wide state})$$



D_1^0 contributions increases with $|\cos\alpha|$
dominates bump for $|\cos\alpha| > 0.75$

D_2^{*0} behaviour is not so obvious
does not contradict to slow decrease

make simultaneous χ^2 fit of these
four and $M(D^+\pi^-)$ histograms
($\Gamma(D_2^{*0}) \equiv 43 \text{ MeV}$ and $h(D_2^{*0}) \equiv -1$)

D_1^0, D_2^{*0} fit results

Masses:

PDG 2006/8

$$M(D_1^0) = 2420.5 \pm 2.1(\text{stat.}) \pm 0.9(\text{syst.}) \quad 2422.3 \pm 1.3 \text{ MeV} \quad \text{good}$$

$$M(D_2^{*0}) = 2469.1 \pm 3.7(\text{stat.})_{-1.3}^{+1.2}(\text{syst.}) \quad 2461.1 \pm 1.6 \text{ MeV} \quad \text{fair}$$

Width:

$$\Gamma(D_1^0) = 53.2 \pm 7.1(\text{stat.})_{-4.9}^{+3.3}(\text{syst.}) \quad 20.4 \pm 1.7 \text{ MeV} \quad \underline{\text{above}}$$

Helicity parameter:

$$h(D_1^0) = 5.9_{-1.7}^{+3.0}(\text{stat.})_{-1.0}^{+2.4}(\text{syst.}) \quad 3 \text{ (HQET)} \quad \text{consistent}$$

Yields:

$$N(D_1^0 \rightarrow D^{*+}\pi^-) = 3110 \pm 340 \implies \mathcal{F}_{D_1^0 \rightarrow D^{*+}\pi^- / D^{*+}} = 10.4 \pm 1.2_{-1.5}^{+0.9} \%$$

$$N(D_2^{*0} \rightarrow D^{*+}\pi^-) = 870 \pm 170 \implies \mathcal{F}_{D_2^{*0} \rightarrow D^{*+}\pi^- / D^{*+}} = 3.0 \pm 0.6 \pm 0.2 \%$$

$$N(D_2^{*0} \rightarrow D^+\pi^-) = 690 \pm 160 \implies \mathcal{F}_{D_2^{*0} \rightarrow D^+\pi^- / D^+} = 7.3 \pm 1.7_{-1.2}^{+0.8} \%$$

convert these fractions to $f(c \rightarrow D_1^0)$, $f(c \rightarrow D_2^{*0})$ and $\frac{\mathcal{B}_{D_2^{*0} \rightarrow D^+\pi^-}}{\mathcal{B}_{D_2^{*0} \rightarrow D^{*+}\pi^-}}$

D_1^0, D_2^{*0} fragm. fractions and D_2^{*0} branching ratios

using $f(c \rightarrow D^{*+})$ and $f(c \rightarrow D^+)$ measured by ZEUS previously:

$$\frac{\mathcal{B}_{D_2^{*0} \rightarrow D^+ \pi^-}}{\mathcal{B}_{D_2^{*0} \rightarrow D^{*+} \pi^-}} = 2.8 \pm 0.8(\text{stat.})_{-0.6}^{+0.5}(\text{syst.}) \quad 2.3 \pm 0.6 \text{ (PDG 2006/8)}$$

from isospin conservation:

$$\mathcal{B}_{D_1^0 \rightarrow D^{*+} \pi^-} = 2/3$$

$$\mathcal{B}_{D_2^{*0} \rightarrow D^{*+} \pi^-} + \mathcal{B}_{D_2^{*0} \rightarrow D^+ \pi^-} = 2/3$$

using isospin conservation and our $f(c \rightarrow D^{*+})$ and $f(c \rightarrow D^+)$:

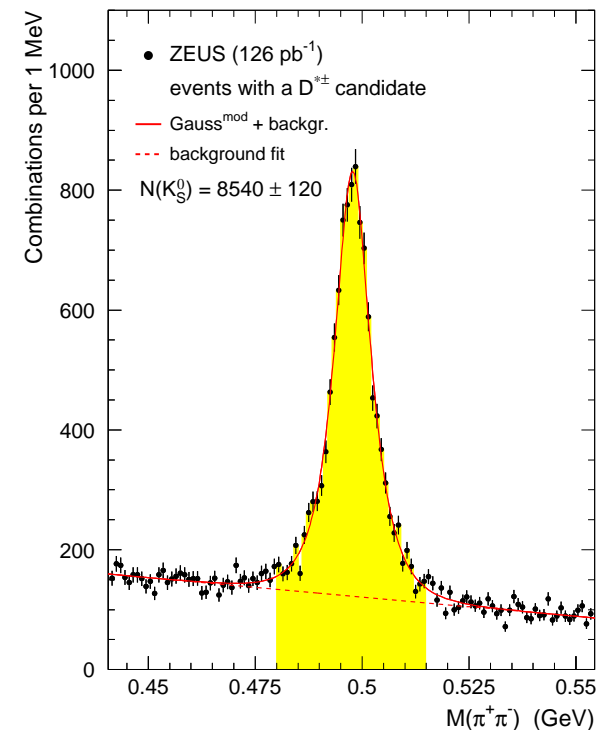
$$f(c \rightarrow D_1^0) = 3.5 \pm 0.4(\text{stat.})_{-0.6}^{+0.4}(\text{syst.}) \%$$

$$f(c \rightarrow D_2^{*0}) = 3.8 \pm 0.7(\text{stat.})_{-0.6}^{+0.5}(\text{syst.}) \%$$

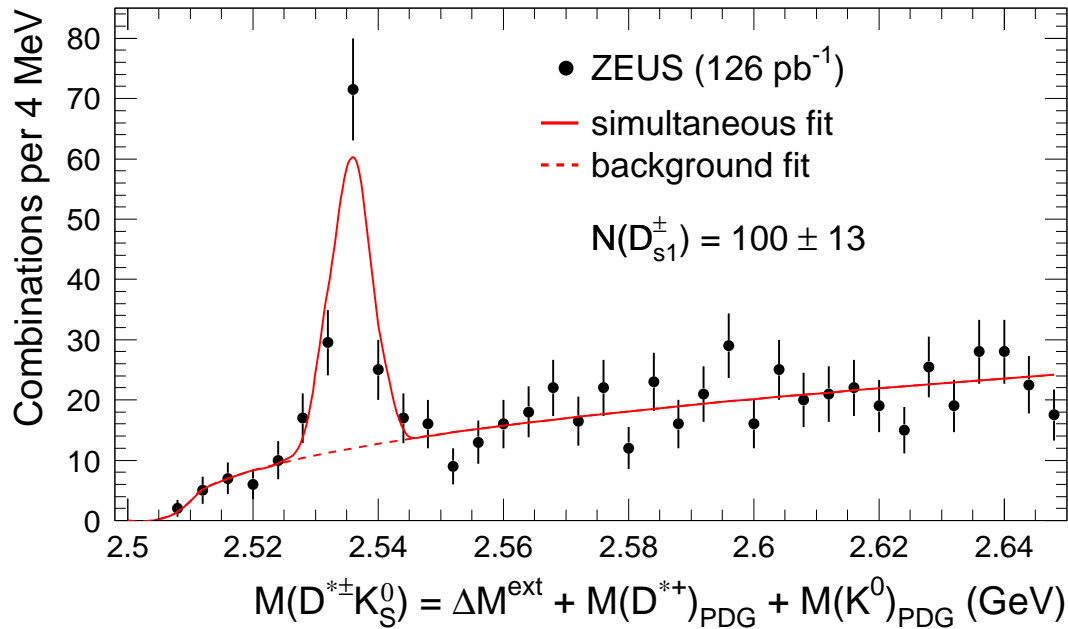
What about charm-strange excited D mesons ?

combine $D^{*\pm}$ with reconstructed $K_s^0 \rightarrow \pi^+ \pi^- \implies$

combine D^0 with an additional charged particle assumed to be K^\pm (soft dE/dx cleaning applied)



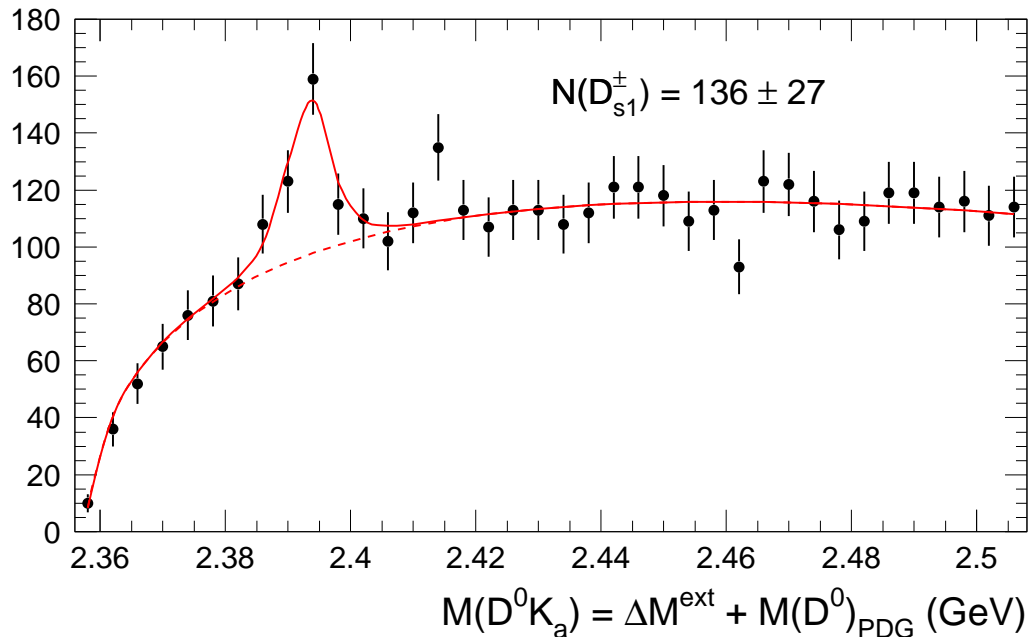
$M(D^{*+}K_s^0)$ and $M(D^0K^+)$ (+c.c.) distributions



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

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

Clear $D_{s1}(2536)^\pm$ signal



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

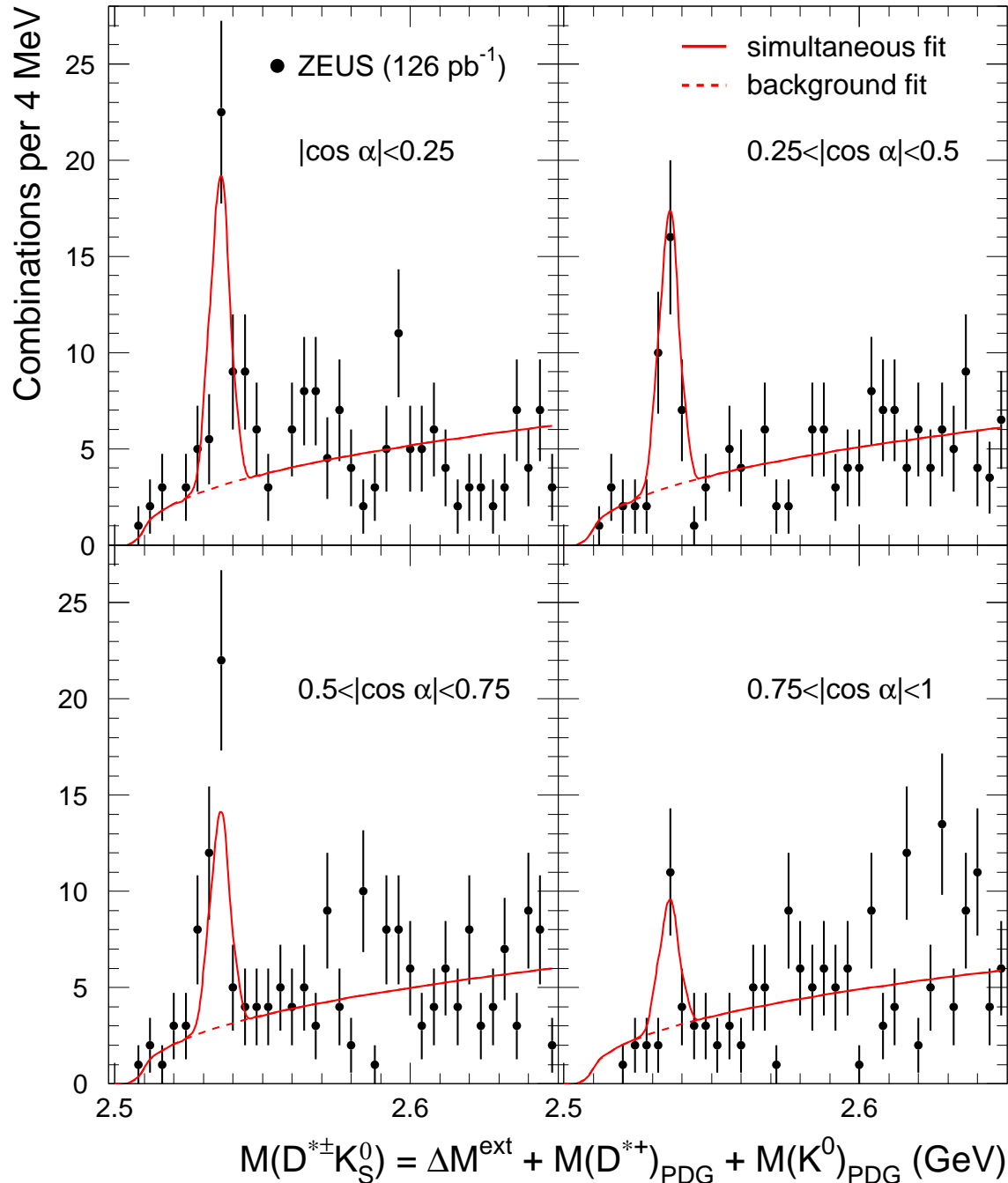
clear feed-down from $D_{s1}^+ \rightarrow D^{*0}K^+$
 (with $D^{*0} \rightarrow D^0\pi^0, D^0\gamma$)

shifted on 142.4 ± 0.2 MeV (MC)

can be described by
 modified Gaussian (MC studies)

(no $D_{s2}(2573)^+ \rightarrow D^0K^+$ signal was observed)

$M(D^{*\pm}K_s^0)$ in 4 helicity intervals



helicity angle α - between π_s and K_s^0 in $D^{*\pm}$ rest frame

$$\frac{dN}{d \cos \alpha} \propto 1 + h \cdot \cos^2 \alpha, \quad h ?$$

HQET predicts:

$$h = 3 \text{ for } D\text{-wave } 1^+$$

$$h = 0 \text{ for } S\text{-wave } 1^+$$

$$h = -1 \text{ for } 1^-, 2^+$$



D_{s1}^+ contributions decreases with $|\cos \alpha|$ that suggests $h < 0$

make combined likelihood fit of $M(D^{*+}K_s^0) \oplus \cos \alpha$ and $M(D^0K^+)$

$M(D^{*+}K_s^0) \oplus \cos \alpha$ and $M(D^0K^+)$ fit results

$$N(D_{s1}^+)_{D^{*+}K_s^0} = 100 \pm 13 \implies \mathcal{F}_{D_{s1}^+ \rightarrow D^{*+}K^0/D^{*+}} = 1.35 \pm 0.18 \pm 0.03 \%$$

$$N(D_{s1}^+)_{D^{*0}K^+} = 136 \pm 27 \implies \mathcal{F}_{D_{s1}^+ \rightarrow D^{*0}K^+/D_{\text{untag}}^0} = 1.28 \pm 0.26 \pm 0.07 \%$$

$$M(D_{s1}^+) = 2535.57_{-0.41}^{+0.44}(\text{stat.}) \pm 0.10(\text{syst.}) \text{ MeV} \quad M(D_{s1}^+)_{\text{PDG}} = 2535.35 \pm 0.34 \text{ MeV}$$

$$h(D_{s1}^+) = -0.74_{-0.17}^{+0.23}(\text{stat.})_{-0.05}^{+0.06}(\text{syst.}) \quad \text{CLEO } (D_{s1}^+ \rightarrow D^{*0}K^+) : h = -0.23_{-0.32}^{+0.40}$$

$$\text{Belle prel.} : h = -0.70 \pm 0.03$$

does not contradict to $h = -1$ (1^- , 2^+) \iff excluded by no decay to D^+K^0

inconsistent with $h = 3$, i.e. D -wave 1^+

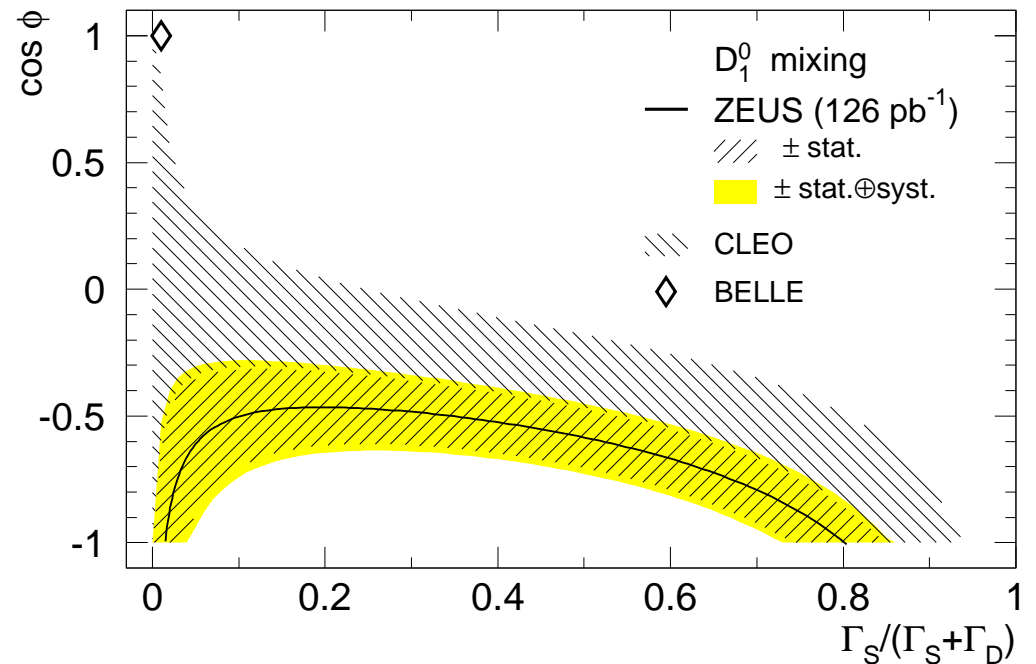
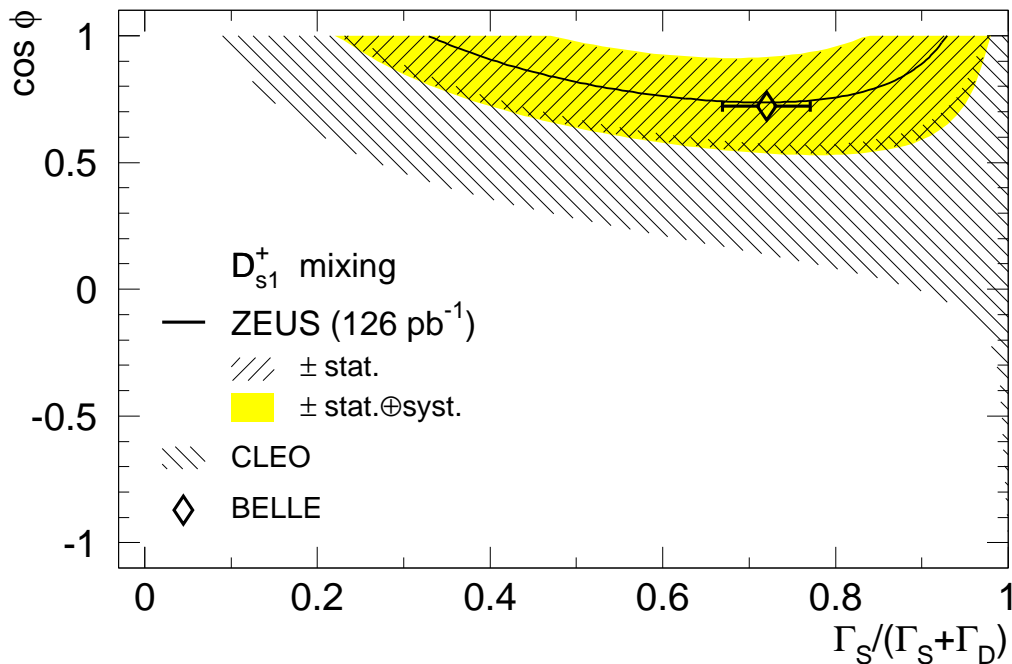
hardly consistent with $h = 0$, i.e. S -wave 1^+

mixture of D - and S -waves, i.e. interf. with $D_{s1}^+(2460)$?

Mixing of D - and S -waves for D_{s1}^+ and D_1^0

$$T^{D_1} = T^S \sin \omega + e^{-i\phi} T^D \cos \omega \quad r = \Gamma_S / (\Gamma_S + \Gamma_D) = \sin^2 \omega$$

$$\frac{dN}{d \cos \alpha} \propto r + (1 - r) \cdot (1 + 3 \cos^2 \alpha) / 2 + \sqrt{2r(1 - r)} \cos \phi (1 - 3 \cos^2 \alpha)$$



$$\cos \phi = \frac{(3-h)/(3+h) - r}{2\sqrt{2r(1-r)}}$$

D_{s1}^+ - sizeable mixing

D_1^0 - can be almost pure D -wave

ZEUS measurement favours negative $\cos \phi$ and large mixing

Can mixing depend from environment ?
larger S -wave admixture \implies larger width

D_{s1}^+ fragm. fraction and ratio of branching ratios

using $f(c \rightarrow D^{*+})$ and $f(c \rightarrow D^0)$ measured by ZEUS previously gives:

$$\frac{\mathcal{B}_{D_{s1}^+ \rightarrow D^{*0} K^+}}{\mathcal{B}_{D_{s1}^+ \rightarrow D^{*+} K^0}} = 2.3 \pm 0.6(\text{stat.}) \pm 0.3(\text{syst.}) \quad 1.27 \pm 0.21 \text{ (PDG)}$$

assuming D_{s1}^+ decay width is saturated by $D^* K$ final states, i.e.:

$$\mathcal{B}_{D_{s1}^+ \rightarrow D^{*+} K^0} + \mathcal{B}_{D_{s1}^+ \rightarrow D^{*0} K^+} = 1 \quad \text{gives:}$$

$$f(c \rightarrow D_{s1}^+) = 1.11 \pm 0.16(\text{stat.})_{-0.10}^{+0.08}(\text{syst.}) \%$$

	$f(c \rightarrow D_1^0)$ [%]	$f(c \rightarrow D_2^{*0})$ [%]	$f(c \rightarrow D_{s1}^+)$ [%]
ZEUS	$3.5 \pm 0.4_{-0.6}^{+0.4}$	$3.8 \pm 0.7_{-0.6}^{+0.5}$	$1.11 \pm 0.16_{-0.10}^{+0.08}$
OPAL	2.1 ± 0.8	5.2 ± 2.6	$1.6 \pm 0.4 \pm 0.3$
ALEPH			$0.94 \pm 0.22 \pm 0.07$

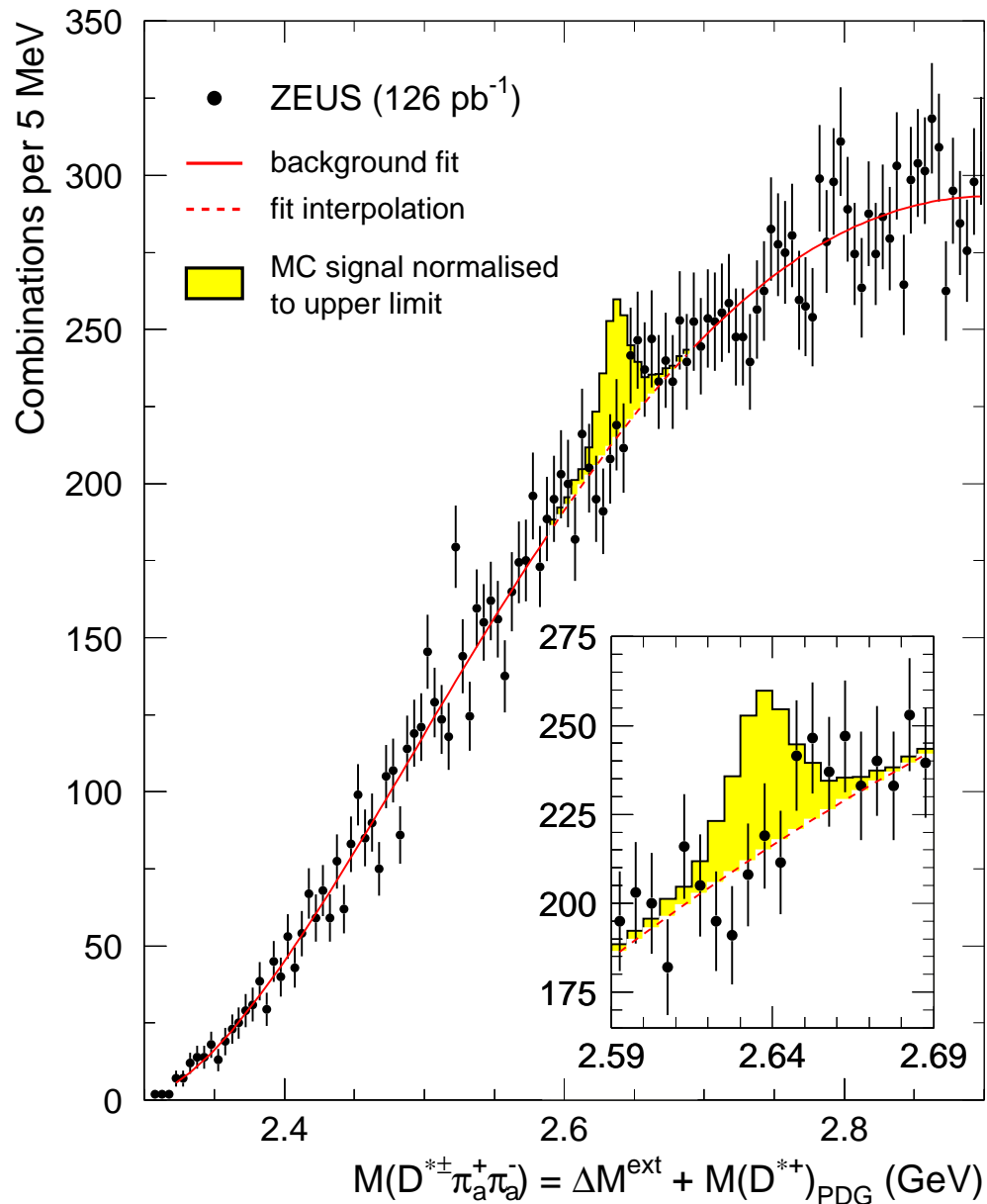
fragm. fractions for excited D mesons in ep and e^+e^- consistent

strangeness suppression for D_1 mesons:

$$\gamma_s^{D_1} = f(c \rightarrow D_{s1}^+) / f(c \rightarrow D_1^0) = 0.31 \pm 0.06(\text{stat.})_{-0.04}^{+0.05}(\text{syst.})$$

agrees well with γ_s^D measured by ZEUS (and others) previously

Search for radially excited $D^{*\prime\pm} \rightarrow D^{*\pm} \pi^+ \pi^-$ meson



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

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

no DELPHI's or other signals

$$N(D^{*\pm} \pi^+ \pi^-)_{2.59-2.69} = 104 \pm 83$$

correcting and using our $f(c \rightarrow D^{*+})$:

$$f(c \rightarrow D^{*\prime+}) \cdot \mathcal{B}_{D^{*\prime+} \rightarrow D^{*+} \pi^+ \pi^-} < 0.4\% \quad (95\% \text{ C.L.})$$

stronger than the 0.9% OPAL limit

	$\mathcal{R}_{D^{*\prime+} \rightarrow D^{*+} \pi^+ \pi^- / D_1^0, D_2^{*0} \rightarrow D^{*+} \pi^-}$
DELPHI, $Z^0 \rightarrow b\bar{b}, c\bar{c}$	$49 \pm 18 \pm 10\%$
OPAL, $Z^0 \rightarrow b\bar{b}, c\bar{c}$	$5 \pm 10 \pm 0.2\%$ $< 22\% \text{ (95\% C.L.)}$
ZEUS, $ep \rightarrow c\bar{c}X$	$4.5 \pm 3.6^{+0.6}_{-0.7}\%$ $< 12\% \text{ (95\% C.L.)}$

Summary

measurement of charm fragmentation function ($D^{*\pm}$) :

clear signature of QCD scaling violation for $\langle z \rangle$ in e^+e^- and ep data

PYTHIA with Bowler and Peterson fragmentation functions

provide good description; $\epsilon = 0.062 \pm 0.007_{-0.004}^{+0.008}$

Peterson parameter for FMNR NLO ($0.079 \pm 0.008_{-0.005}^{+0.010}$) is larger than that (0.035) obtained by Nason and Oleari from fit to ARGUS data

Kartvelishvili fragmentation function provides best data description

study of excited D mesons :

sizeable and consistent amounts of excited D mesons in e^+e^- and ep data

strangeness suppression for D_1 mesons, $\gamma_s^{D_1} = 0.31 \pm 0.06_{-0.04}^{+0.05}$,

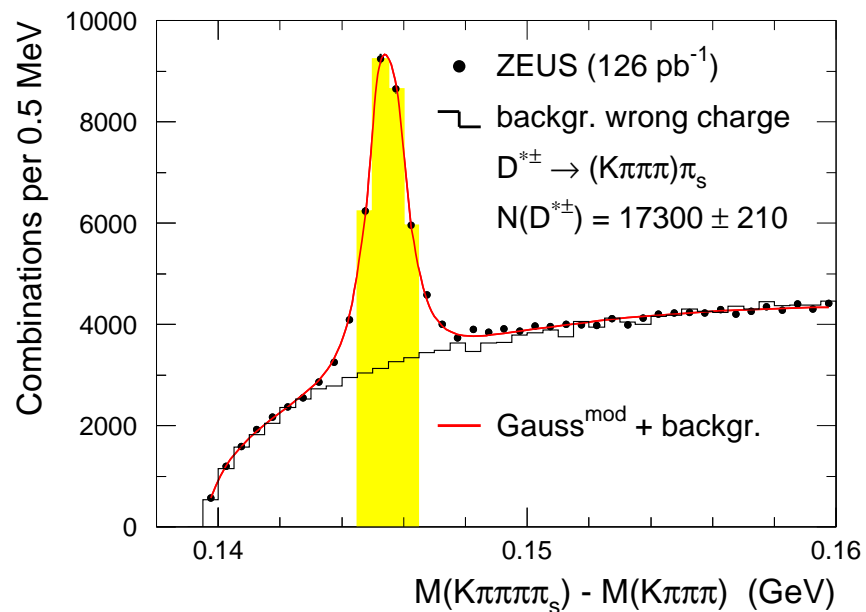
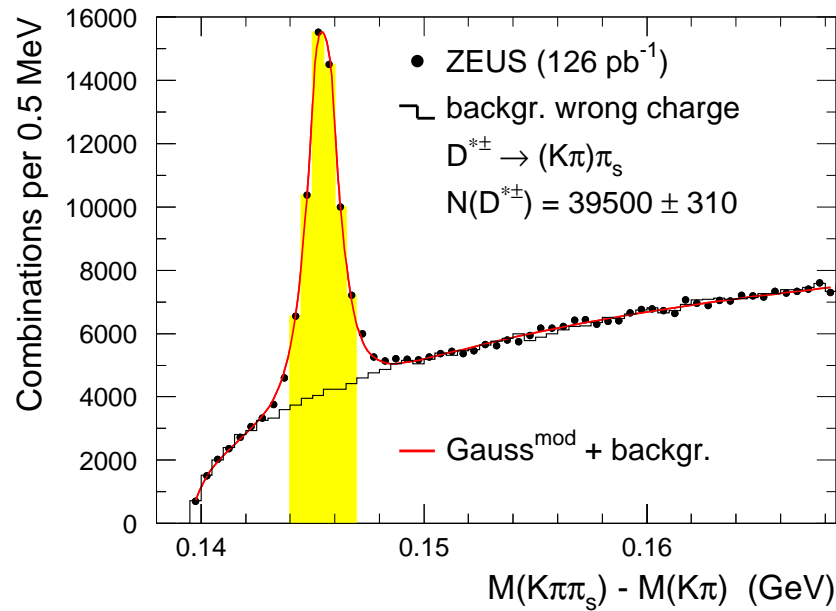
agrees well with γ_s^D measured by ZEUS (and others) previously

significant contrib. of both D - and S -wave amplit. to $D_{s1}^+ \rightarrow D^{*+} K_S^0$ decay

$\Gamma(D_1^0)$ is larger than in prev. measurements (larger S -wave admixture ?)

the strongest world limit: $f(c \rightarrow D^{*'+}) \cdot \mathcal{B}_{D^{*'+} \rightarrow D^{*+} \pi^+ \pi^-} < 0.4\%$ (95% C.L.)

$D^{*\pm}$ reconstruction (similar to paper on Θ_c^0 search)



95-00 data (126 pb^{-1})

two D^* decay channels:

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

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

$$p_T(D^*) > 1.35 \text{ GeV for } (K\pi)\pi_s$$

$$p_T(D^*) > 2.8 \text{ GeV for } (K\pi\pi\pi)\pi_s$$

$$|\eta(D^*)| < 1.6 \text{ for both channels}$$

$$dE/dx : l_K = \text{Prob}(K) > 3\%$$

$$l_\pi = \text{Prob}(\pi) > 1\%$$

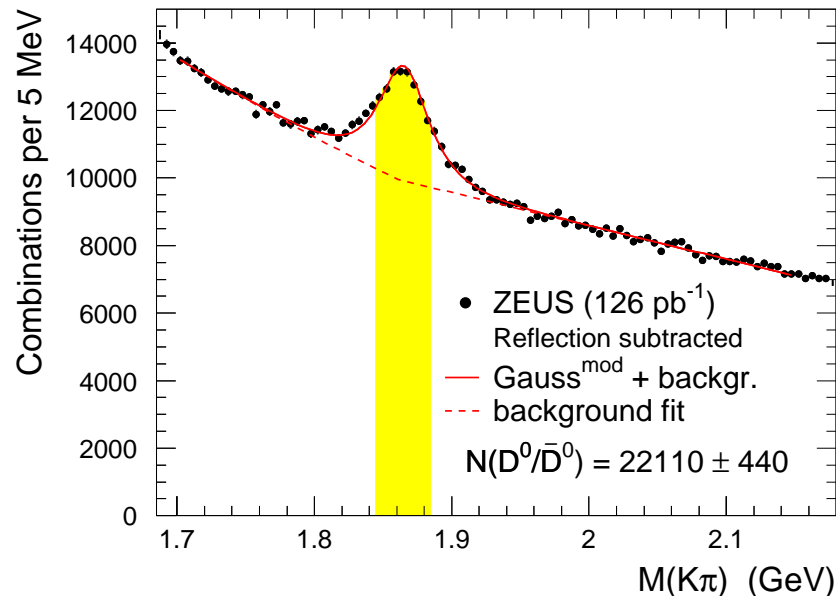
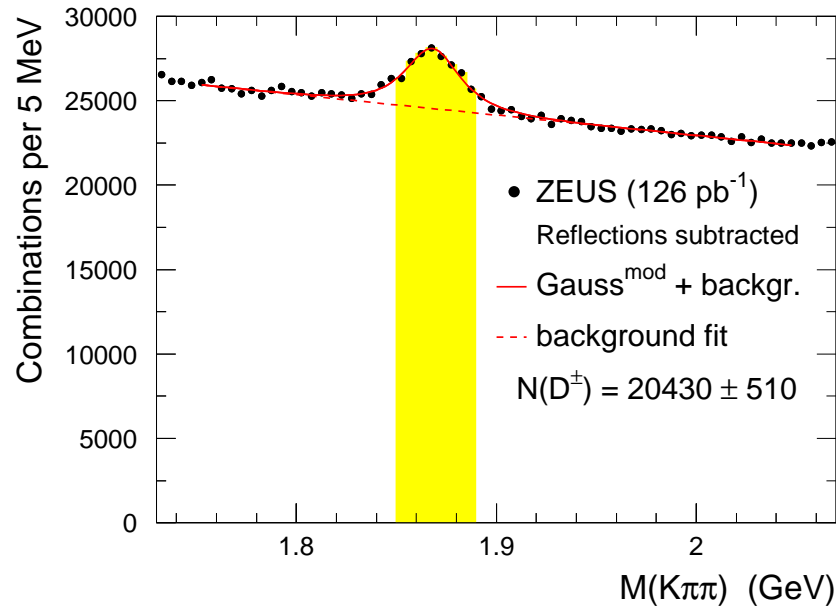
In the yellow bands after
after wrong-charge subtraction:

$$N(D^{*\pm}) \sim 56800$$

(multiple counting excluded)

Only $D^{*\pm}$ candidates from the bands
were used for excited D meson studies

D^\pm and D^0 reconstruction (similar to paper on FF)



95-00 data (126 pb⁻¹)

$$p_T(D^\pm, D^0)/E_T^{\theta > 10^\circ} > 0.25$$

$$dE/dx : l_K > 3\%, l_\pi > 1\%$$

$$D^+ \rightarrow K^- \pi^+ \pi^+ (+c.c.)$$

$$p_T(D^\pm) > 2.8 \text{ GeV}, |\eta(D^\pm)| < 1.6$$

$$\text{Band: } 1.850 < M(K\pi\pi) < 1.890 \text{ GeV}$$

$$\text{in the band: } N(D^\pm) \sim 20400$$

$$D^0 \rightarrow K^- \pi^+ (+c.c.)$$

$$p_T(D^0) > 2.8 \text{ GeV}, |\eta(D^0)| < 1.6$$

only D^0 's w/o Δ_M tag (not from $D^{*\pm}$)
reflection due to inv. mass assign. subtr.

$$\text{Band: } 1.845 < M(K\pi) < 1.885 \text{ GeV}$$

$$\text{in the band: } N(D^0) \sim 22100$$

Only D^\pm and D^0 candidates from the bands
were used for excited D meson studies

D_1^0, D_2^{*0} fit procedure

Simultaneous χ^2 fit of $M(D^\pm\pi_a)$ and $M(D^{*\pm}\pi_a)$ in 4 helicity intervals

15 free parameters

3 signals: relativistic D-wave Breit-Wigner function convoluted with Gaussian resolution function with width fixed to MC predictions
 $\sigma_{\text{res}} = 5.6 \text{ MeV}$ and 7.2 MeV for $M(D^{*\pm}\pi_a)$ and $M(D^\pm\pi_a)$, respectively

acceptance and resolution dependences from $M(D^{*\pm}\pi_a)$ or $M(D^\pm\pi_a)$ and acceptance dependence from helicity angle (compatible with no dependence) were obtained from MC and corrected for in the fit function \Leftarrow small effect

to stabilise fit: $\Gamma(D_2^{*0}) \equiv 43 \text{ MeV}$ and $R(D_2^{*0}) \equiv -1$

2 backgrounds: $x^a \exp(-bx + cx^2)$, where $x = \Delta M^{\text{ext}} - m_\pi$

feed-downs from $D_1^0, D_2^{*0} \rightarrow D^{*+}\pi^-$ to $M(D^+\pi_a)$ were added to the fit function with relative yields taken from MC (7%) \Leftarrow small effect

wide $D_1(2430)^0$ and $D_0^*(2400)^0$ states were added with the world average parameters

$D_1(2430)^0$ yield was set to that of the narrow $D_1(2420)^0$

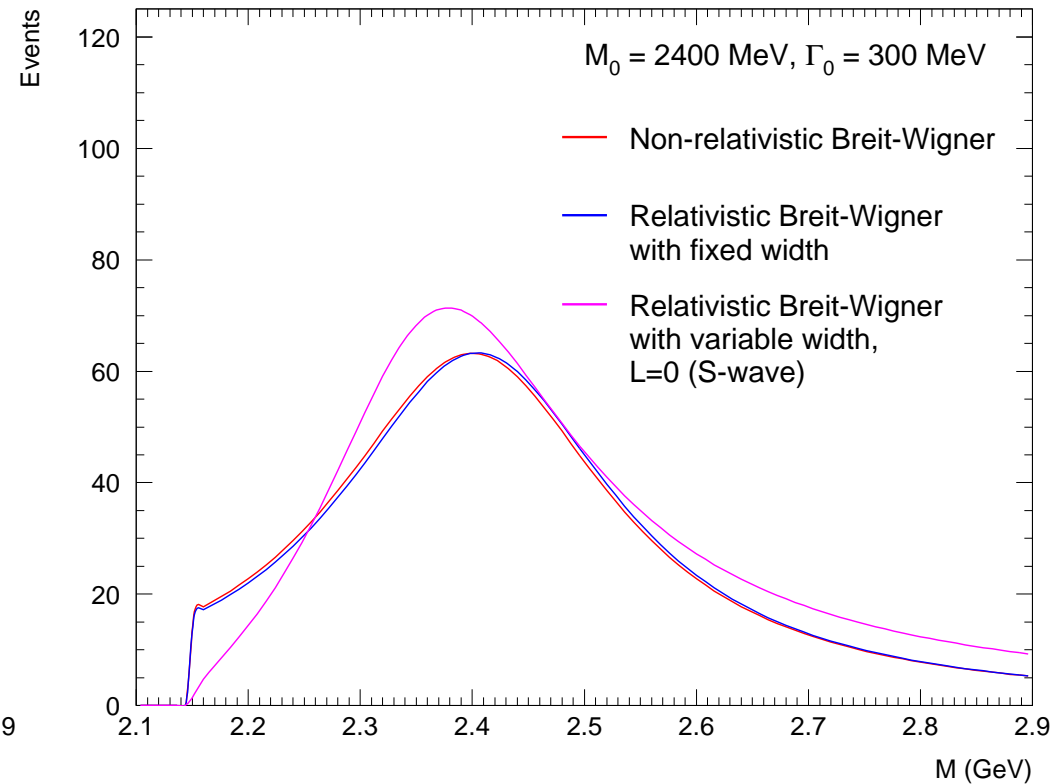
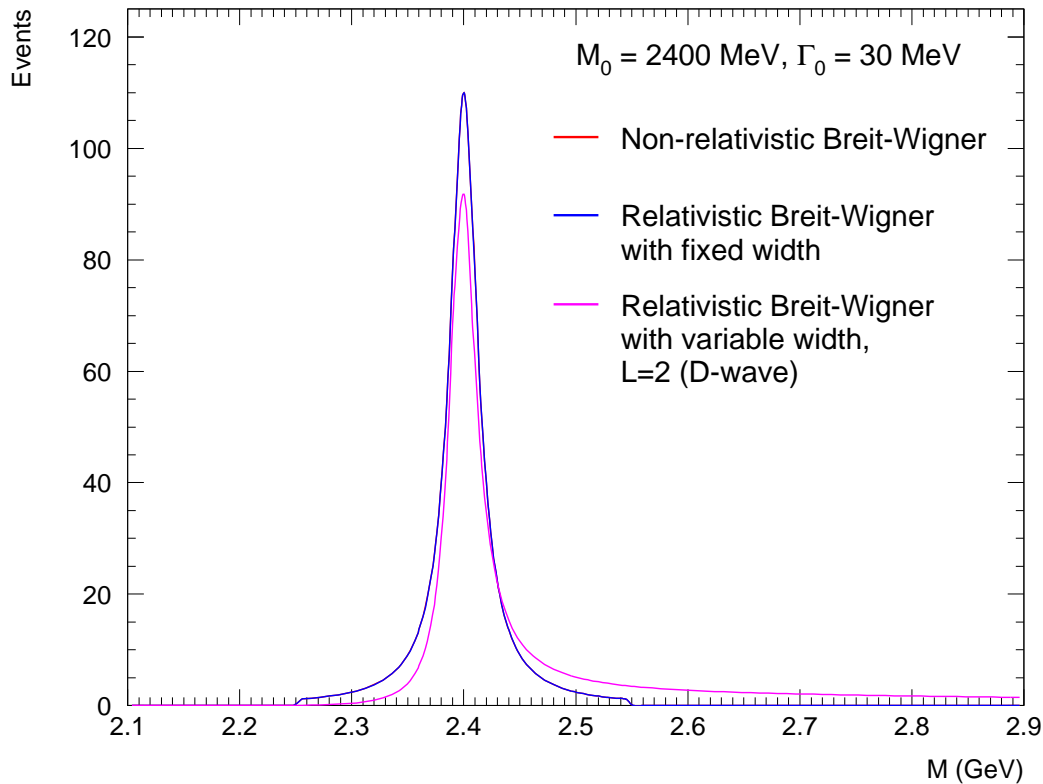
$D_0^*(2400)^0$ yield was set to 1.7 of the $D_2^{*0} \rightarrow D^+\pi^-$ yield as observed by FOCUS

this rate, 1.7, is a sum of true $D_0^*(2400)^0$ and a feed-down from $D_1(2430)^0$

less than one σ effect on $N(D_1^0)$ and $R(D_1^0)$

$$\chi^2/NDF = 913/925 = 0.98$$

Relativistic Breit-Wigner with variable width



$$\frac{dN}{dM} \propto \frac{M \Gamma(M)}{(M^2 - M_0^2)^2 + M_0^2 \Gamma^2(M)} \oplus \text{Gauss}(\sigma_{res})$$

$$\Gamma(M) = \Gamma_0 \cdot \frac{M_0}{M} \cdot \left(\frac{p}{p_0}\right)^{2L+1} \cdot F_L^2(p, p_0)$$

$$F_L^2(p, p_0) = \frac{9 + 3(p_0 r)^2 + (p_0 r)^4}{9 + 3(p r)^2 + (p r)^4}, \quad r = 1.6 \text{ GeV}^{-1} \text{ for charm hadrons}$$

\$D_1^0, D_2^{*0}\$ fractions

corrected ratios (factors \$\sim 2\$)

extrap. to full phase space (\$\sim 1.1\$ and \$\sim 1.2\$)

$$\mathcal{F}_{D_1^0 \rightarrow D^{*+}\pi^- / D^{*+}} = 10.4 \pm 1.2(\text{stat.})_{-1.5}^{+0.9}(\text{syst.}) \%$$

$$11.6 \pm 1.3(\text{stat.})_{-1.7}^{+1.1}(\text{syst.}) \%$$

$$\mathcal{F}_{D_2^{*0} \rightarrow D^{*+}\pi^- / D^{*+}} = 3.0 \pm 0.6(\text{stat.}) \pm 0.2(\text{syst.}) \%$$

$$3.3 \pm 0.6(\text{stat.}) \pm 0.2(\text{syst.}) \%$$

$$\mathcal{F}_{D_2^{*0} \rightarrow D^+\pi^- / D^+} = 7.3 \pm 1.7(\text{stat.})_{-1.2}^{+0.8}(\text{syst.}) \%$$

$$8.6 \pm 2.0(\text{stat.})_{-1.4}^{+1.1}(\text{syst.}) \%$$

in full phase space:

$$\mathcal{F}_{D_1^0 \rightarrow D^{*+}\pi^- / D^{*+}}^{\text{extr}} = \frac{f(c \rightarrow D_1^0)}{f(c \rightarrow D^{*+})} \cdot \mathcal{B}_{D_1^0 \rightarrow D^{*+}\pi^-}$$

$$\mathcal{F}_{D_2^{*0} \rightarrow D^{*+}\pi^- / D^{*+}}^{\text{extr}} = \frac{f(c \rightarrow D_2^{*0})}{f(c \rightarrow D^{*+})} \cdot \mathcal{B}_{D_2^{*0} \rightarrow D^{*+}\pi^-}$$

$$\mathcal{F}_{D_2^{*0} \rightarrow D^+\pi^- / D^+}^{\text{extr}} = \frac{f(c \rightarrow D_2^{*0})}{f(c \rightarrow D^+)} \cdot \mathcal{B}_{D_2^{*0} \rightarrow D^+\pi^-}$$

re-writing 1st and solving 2 last equations:

$$f(c \rightarrow D_1^0) = \frac{\mathcal{F}_{D_1^0 \rightarrow D^{*+}\pi^- / D^{*+}}^{\text{extr}}}{\mathcal{B}_{D_1^0 \rightarrow D^{*+}\pi^-}} \cdot f(c \rightarrow D^{*+})$$

$$f(c \rightarrow D_2^{*0}) = \frac{\mathcal{F}_{D_2^{*0} \rightarrow D^{*+}\pi^- / D^{*+}}^{\text{extr}} \cdot f(c \rightarrow D^{*+}) + \mathcal{F}_{D_2^{*0} \rightarrow D^+\pi^- / D^+}^{\text{extr}} \cdot f(c \rightarrow D^+)}{\mathcal{B}_{D_2^{*0} \rightarrow D^{*+}\pi^-} + \mathcal{B}_{D_2^{*0} \rightarrow D^+\pi^-}}$$

$$\frac{\mathcal{B}_{D_2^{*0} \rightarrow D^+\pi^-}}{\mathcal{B}_{D_2^{*0} \rightarrow D^{*+}\pi^-}} = \frac{\mathcal{F}_{D_2^{*0} \rightarrow D^+\pi^- / D^+}^{\text{extr}} \cdot f(c \rightarrow D^+)}{\mathcal{F}_{D_2^{*0} \rightarrow D^{*+}\pi^- / D^{*+}}^{\text{extr}} \cdot f(c \rightarrow D^{*+})}$$

D_{s1}^+ fractions

corrected ratios (factors ~ 2)

$$\mathcal{F}_{D_{s1}^+ \rightarrow D^{*+}K^0/D^{*+}} = 1.35 \pm 0.18(\text{stat.}) \pm 0.03(\text{syst.}) \%$$

$$\mathcal{F}_{D_{s1}^+ \rightarrow D^{*0}K^+/D_{\text{untag}}^0} = 1.28 \pm 0.26(\text{stat.}) \pm 0.07(\text{syst.}) \%$$

extrap. to full phase space (~ 1.2 and ~ 1.5)

$$1.67 \pm 0.22(\text{stat.}) \pm 0.07(\text{syst.}) \%$$

$$1.93 \pm 0.40(\text{stat.})_{-0.16}^{+0.12}(\text{syst.}) \%$$

in full phase space:

$$\mathcal{F}_{D_{s1}^+ \rightarrow D^{*+}K^0/D^{*+}}^{\text{extr}} = \frac{f(c \rightarrow D_{s1}^+)}{f(c \rightarrow D^{*+})} \cdot \mathcal{B}_{D_{s1}^+ \rightarrow D^{*+}K^0}$$

$$\mathcal{F}_{D_{s1}^+ \rightarrow D^{*0}K^+/D_{\text{untag}}^0}^{\text{extr}} = \frac{f(c \rightarrow D_{s1}^+)}{f(c \rightarrow D_{\text{untag}}^0)} \cdot \mathcal{B}_{D_{s1}^+ \rightarrow D^{*0}K^+}$$

solving system of 2 equations:

$$f(c \rightarrow D_{s1}^+) = \frac{\mathcal{F}_{D_{s1}^+ \rightarrow D^{*+}K^0/D^{*+}}^{\text{extr}} \cdot f(c \rightarrow D^{*+}) + \mathcal{F}_{D_{s1}^+ \rightarrow D^{*0}K^+/D_{\text{untag}}^0}^{\text{extr}} \cdot f(c \rightarrow D_{\text{untag}}^0)}{\mathcal{B}_{D_{s1}^+ \rightarrow D^{*+}K^0} + \mathcal{B}_{D_{s1}^+ \rightarrow D^{*0}K^+}}$$

$$\frac{\mathcal{B}_{D_{s1}^+ \rightarrow D^{*0}K^+}}{\mathcal{B}_{D_{s1}^+ \rightarrow D^{*+}K^0}} = \frac{\mathcal{F}_{D_{s1}^+ \rightarrow D^{*0}K^+/D_{\text{untag}}^0}^{\text{extr}} \cdot f(c \rightarrow D_{\text{untag}}^0)}{\mathcal{F}_{D_{s1}^+ \rightarrow D^{*+}K^0/D^{*+}}^{\text{extr}} \cdot f(c \rightarrow D^{*+})}$$