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

Leonid Gladilin

(SINP MSU)

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O U T L I N E :

Charm Factory HERA

charm fragmentation, JHEP04 (2009) 089

- QCD scaling violation for $< z >$
- fragmentation with LL MC
- fragmentation with FO NLO

excited D mesons, EPJC60 (2009) 25

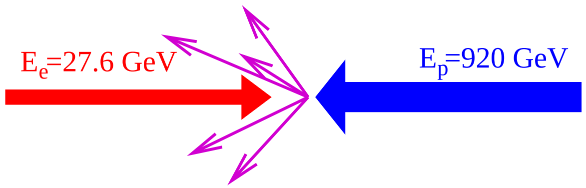
- $D_1^0, D_2^{*0} \rightarrow D^{*+}\pi^-$; $D_2^{*0} \rightarrow D^+\pi^-$
- $D_{s1}^+ \rightarrow D^{*+}K_s^0, D^{*0}K^+$
- search for $D^{*\prime +} \rightarrow D^{*+}\pi^+\pi^-$

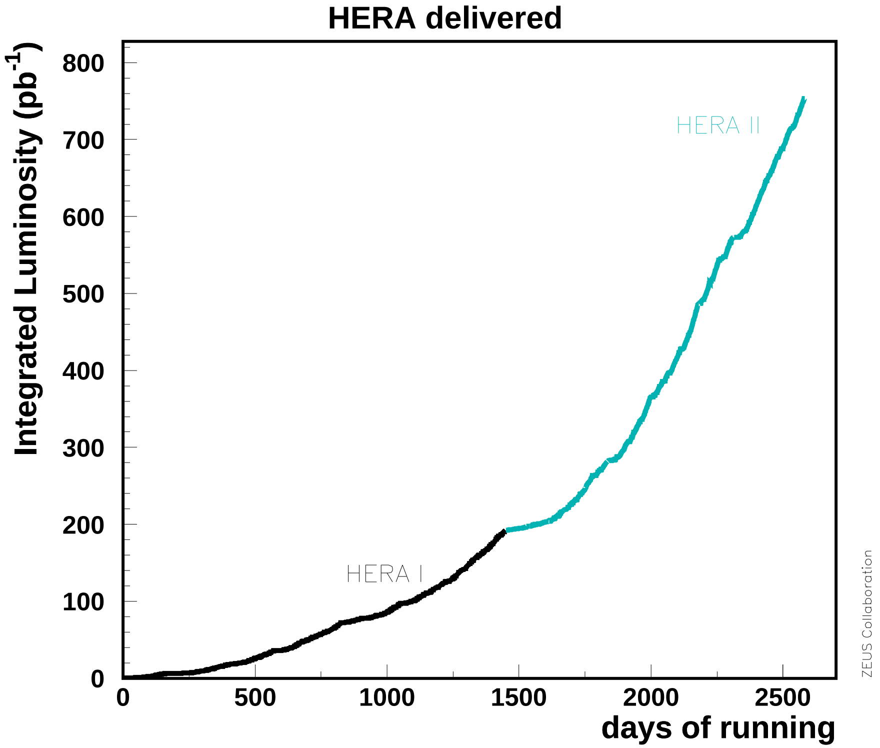
Summary

B A C K U P :

- 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





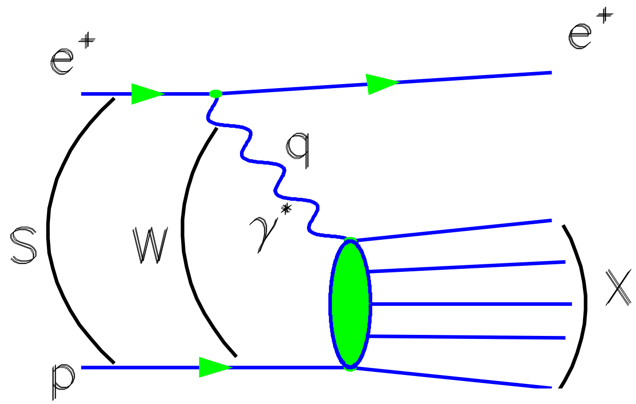
	HERA 1992-2000	HERA II 2003-2007
$\sqrt{s}$	320 **(300)**	320 **GeV**
$\mathcal{L}$	$1.5 \cdot 10^{31}$	$7 \cdot 10^{31}\, cm^{-2}\, s^{-1}$
$\mathcal{L}_{int}$	0.13	$0.37\, fb^{-1}$

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

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

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

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



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

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

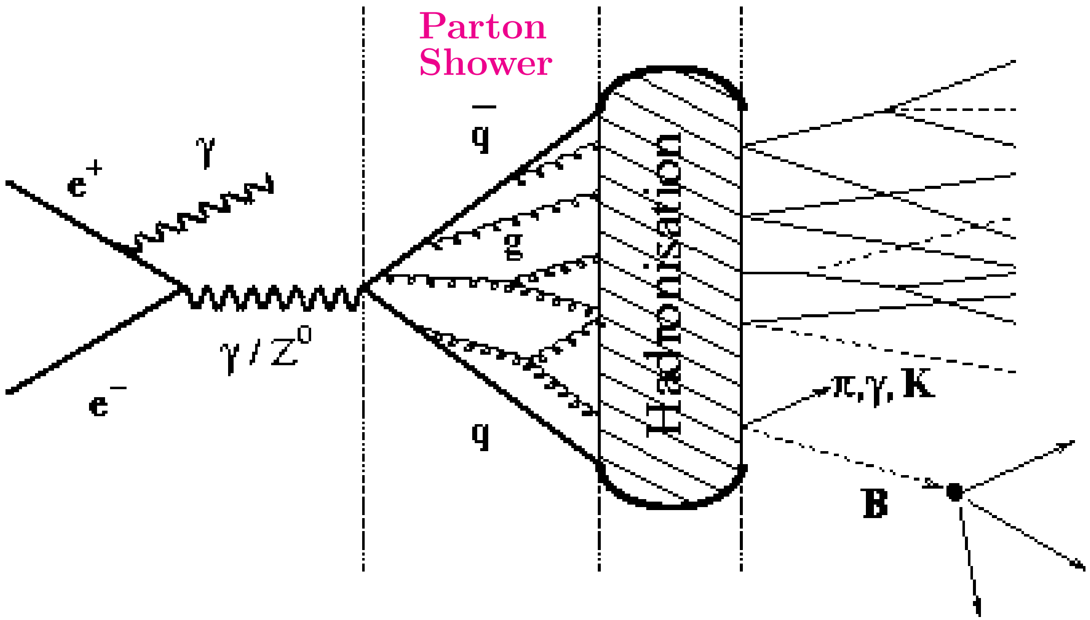
$$x = \frac{Q^2}{2qP} \cong \frac{Q^2}{sy}$$

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

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

Heavy Quark fragmentation

Production   Fragmentation   Decays



HQ fragmentation is hard

harder for larger m_Q

e.g., for Peterson param.:

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

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

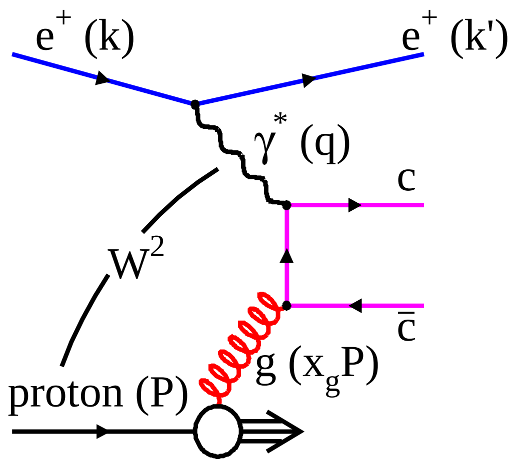
pQCD is applicable to "initial" Q-fragmentation: LO, NLO, LL, NLL, ...

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

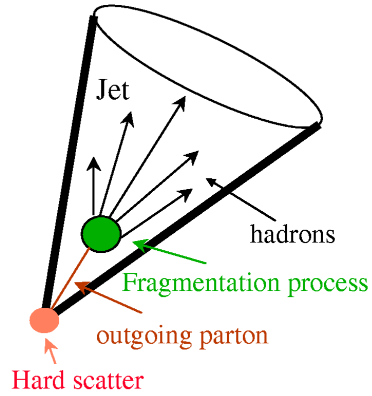
Is the pQCD calculation with its universal NP fragmentation
applic. to $Q\bar{Q}$ production at different scales and colour states ?



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

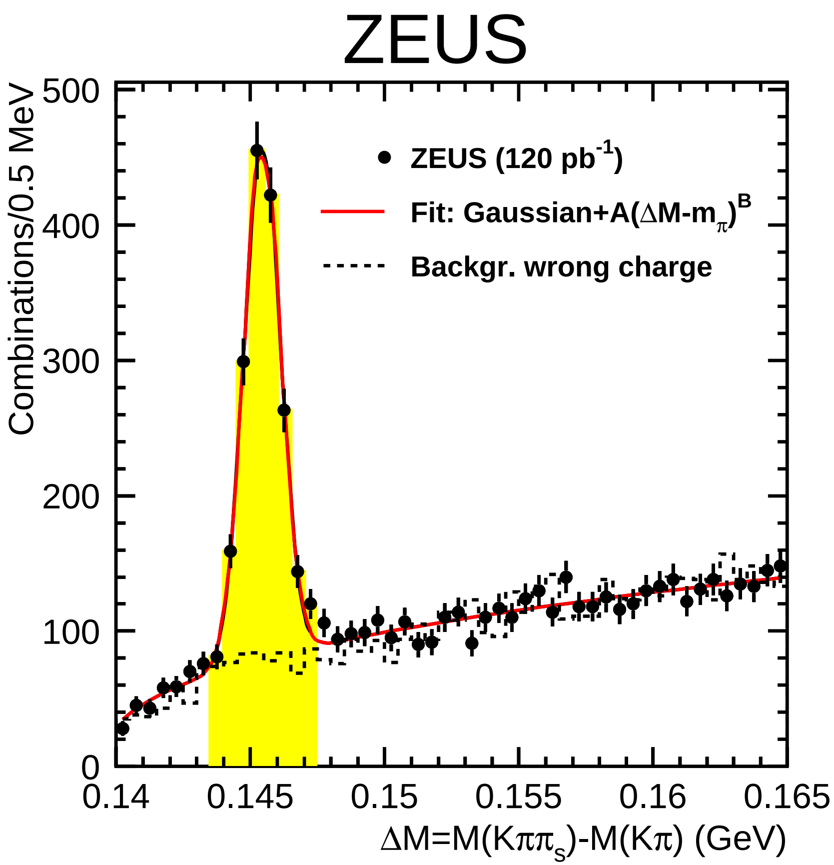
In e^+e^- annihilations, $D^{*\pm}$ energy is related to $\sqrt{s}/2$

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



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

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



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

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

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

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

measured in range $0.16 < z < 1$

beauty contribution subtracted

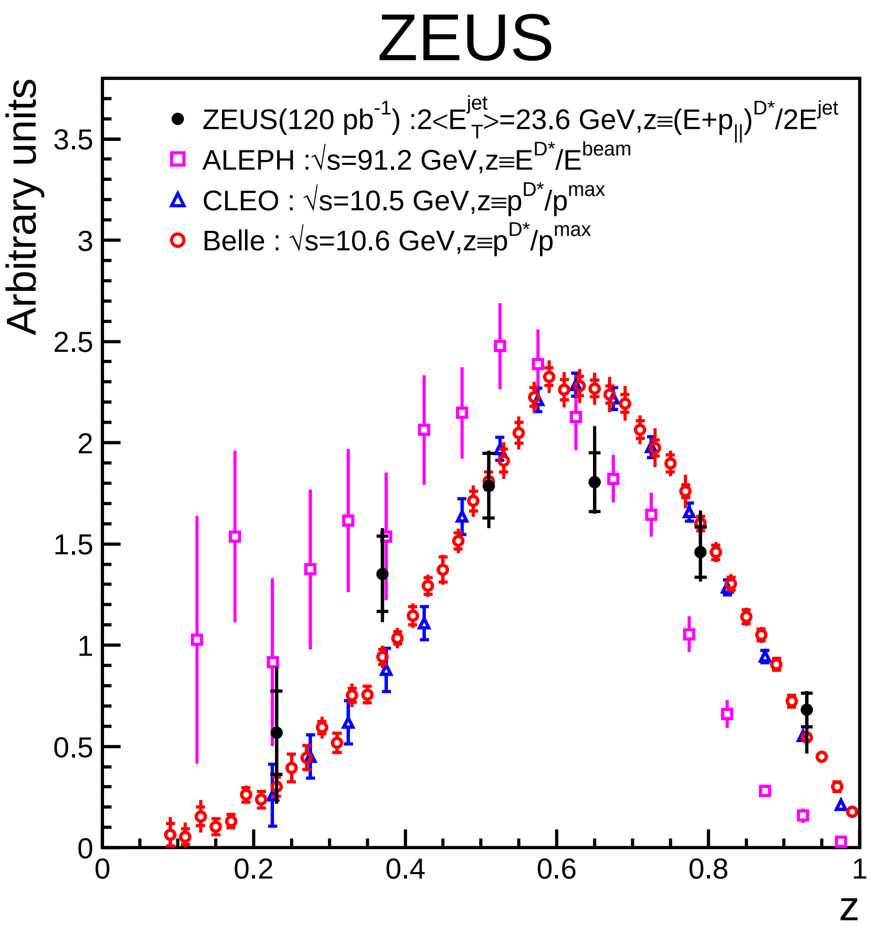
correcting to $0 < z < 1$ gives

$< z >= 0.565 \pm 0.024 \pm 0.028$

at scale $< E_T^{\mathrm{jet}} > \times 2 = 23.6\,\mathrm{GeV}$

QCD scaling violation in charm fragmentation

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

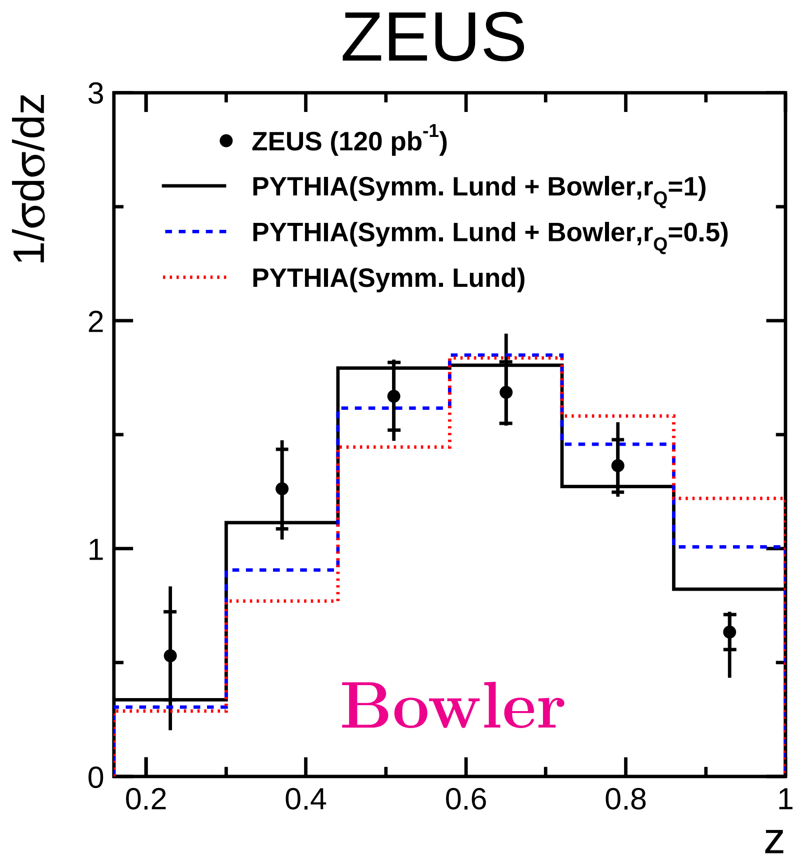


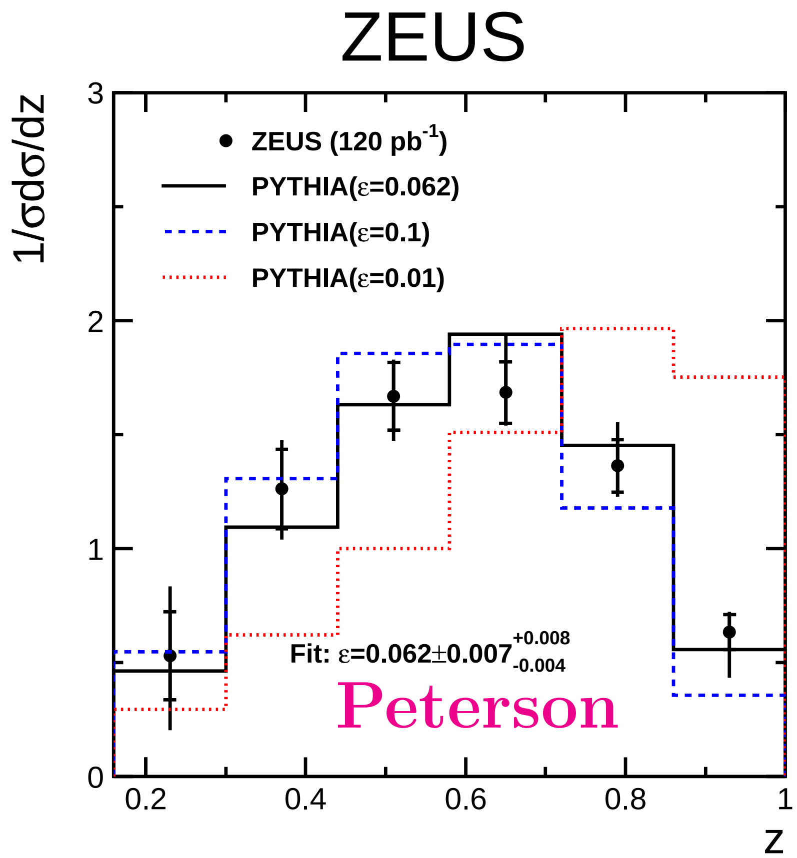
expected QCD scaling violation

larger scale $\Longrightarrow$ 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





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

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

$r_Q = 1$ (default) is preferable

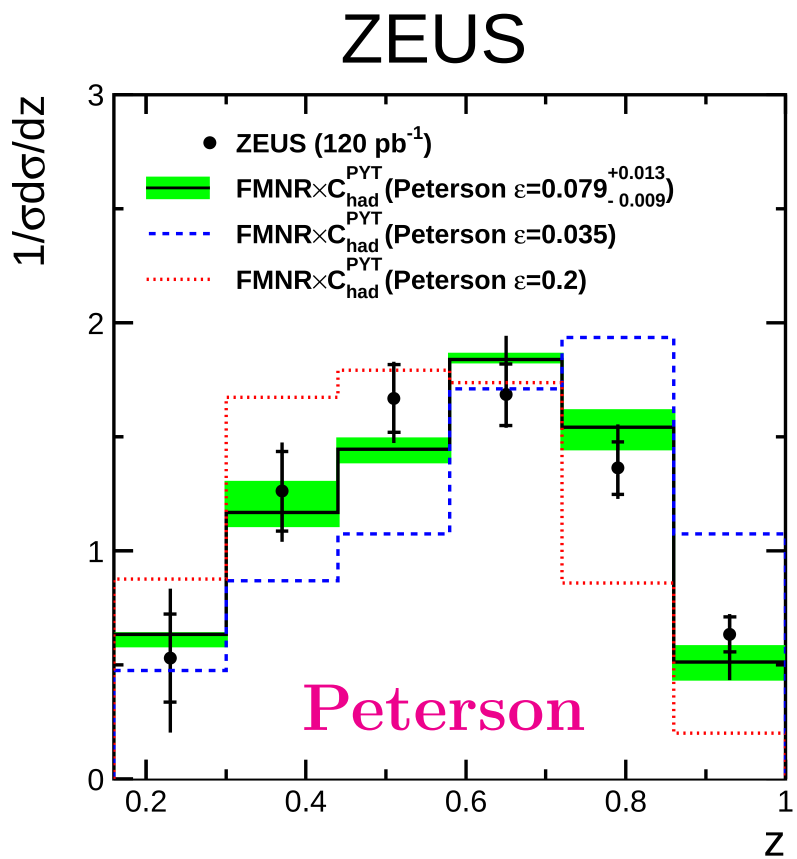
$\epsilon = 0.062 \pm 0.007^{+0.008}_{-0.004}$ (ZEUS, γp)

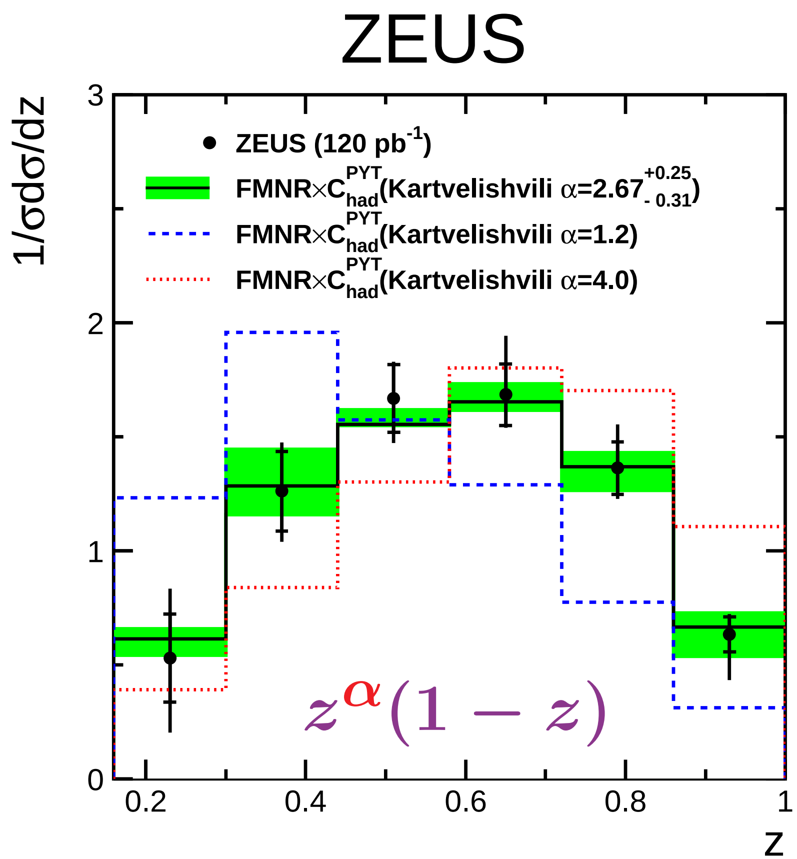
$0.049^{+0.012}_{-0.010} / 0.061^{+0.011}_{-0.009}$ (H1, DIS, scale$\sim$ 10 GeV)

$\epsilon = 0.05$ (PYTHIA default)

Nason, Oleari $\Longrightarrow$ $\epsilon = 0.053$ (LL fit to ARGUS data)

Charm fragmentation with fixed order NLO





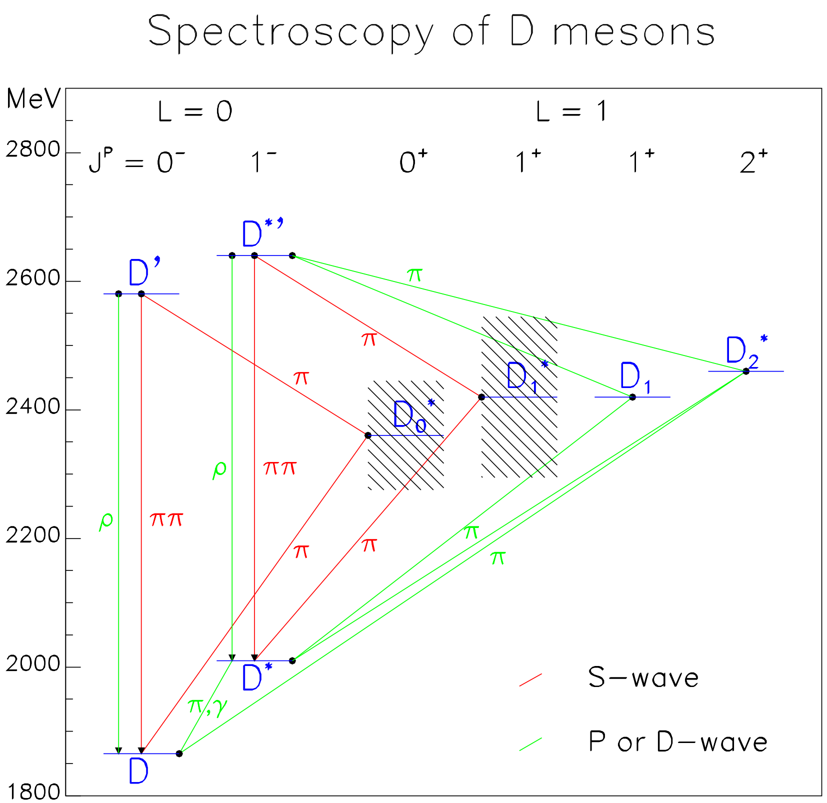
$\epsilon = 0.079 \pm 0.008^{+0.010}_{-0.005}$ (ZEUS) $\alpha = 2.67 \pm 0.18^{+0.17}_{-0.25}$ (ZEUS, γp)

$0.068^{+0.015}_{-0.013}/0.034^{+0.004}_{-0.004}$ (bad χ^2) (H1) $3.3 \pm 0.4/3.8 \pm 0.3$ (H1, DIS)

$\epsilon = 0.035$ (NLO fit to ARGUS data) $\Longleftarrow$ Nason, Oleari

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

Excited D mesons, 20th century



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

doublet with $j = L + s = 3/2$,

D-wave decays $\Longrightarrow$ narrow states

doublet with $j = L + s = 1/2$,

S-wave decays $\Longrightarrow$ wide states

s - spin of the light quark

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

Narrow states are know 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 $D^{*\prime}(2640)^{\pm} \rightarrow D^{*\pm}\pi^+\pi^-$

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

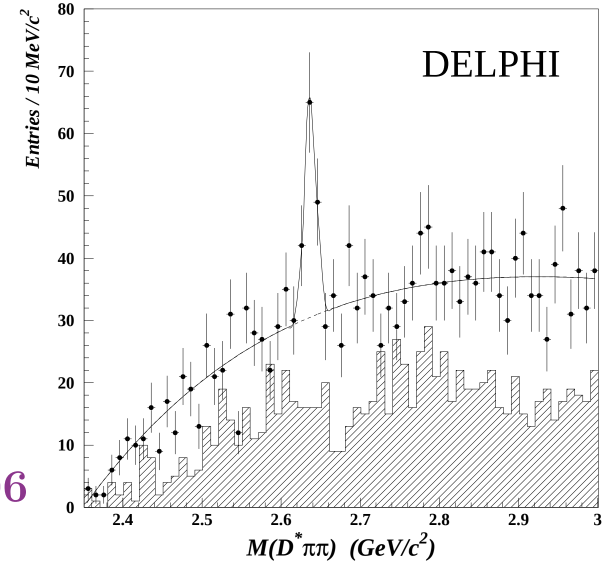
   large uncertainties in parameters and yields

3) DELPHI observation of radially excited $D^{*\prime}$ 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

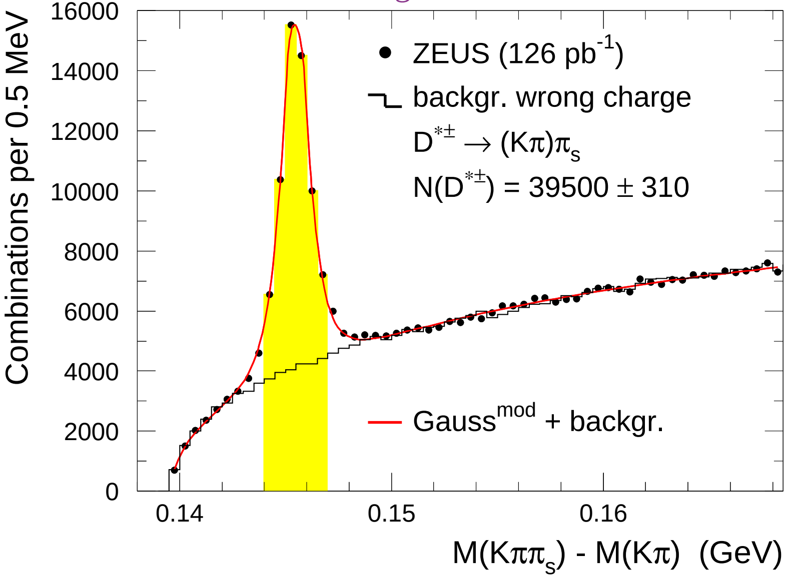
   contribute $20 - 30\%$ of D/D^* production
   set by default to zero (!) in Lund MC generators

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

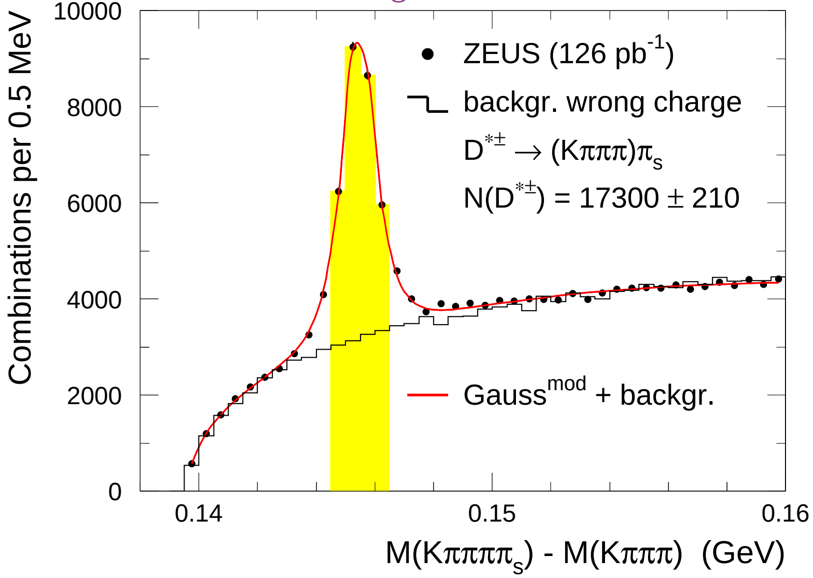
$D^{*\pm}$, $D^{\pm}$ and D^0 reconstruction

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

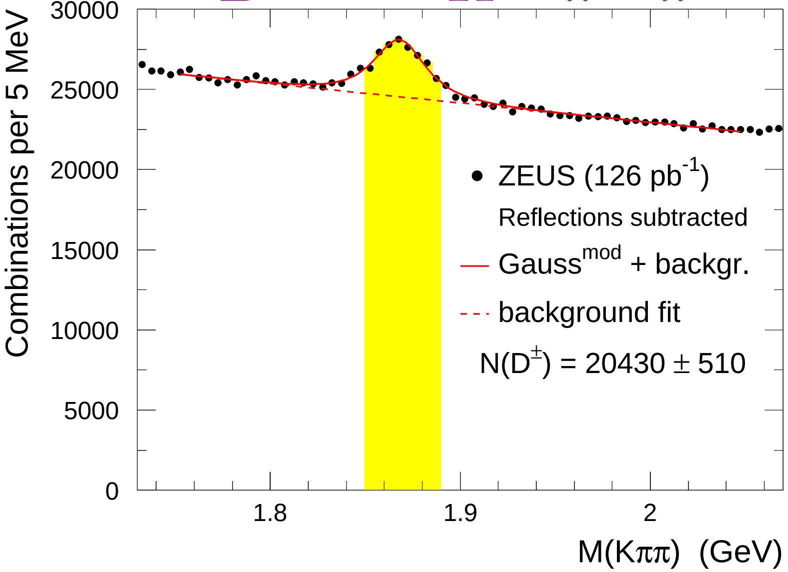
$D^{*+} \rightarrow D^0 \pi_s^+ \rightarrow (K^- \pi^+) \pi_s^+$



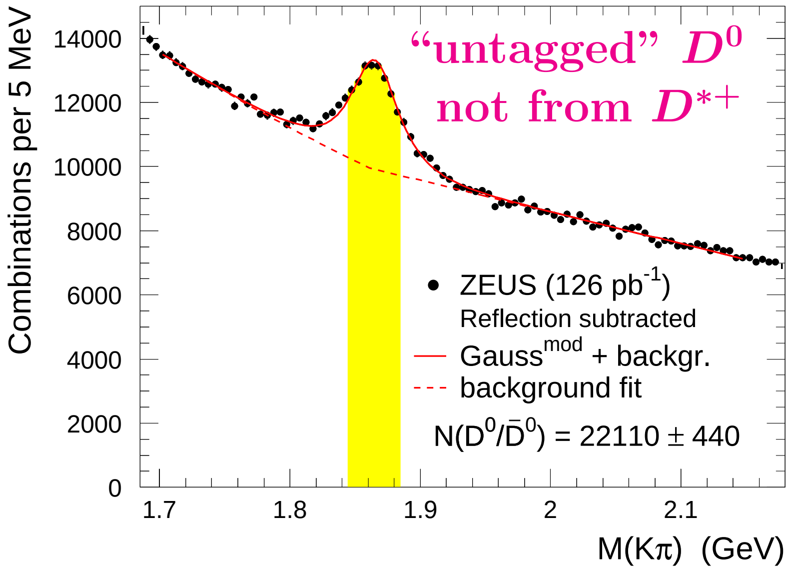
$D^{*+} \rightarrow D^0 \pi_s^+ \rightarrow (K^- \pi^+ \pi^+ \pi^-) \pi_s^+$



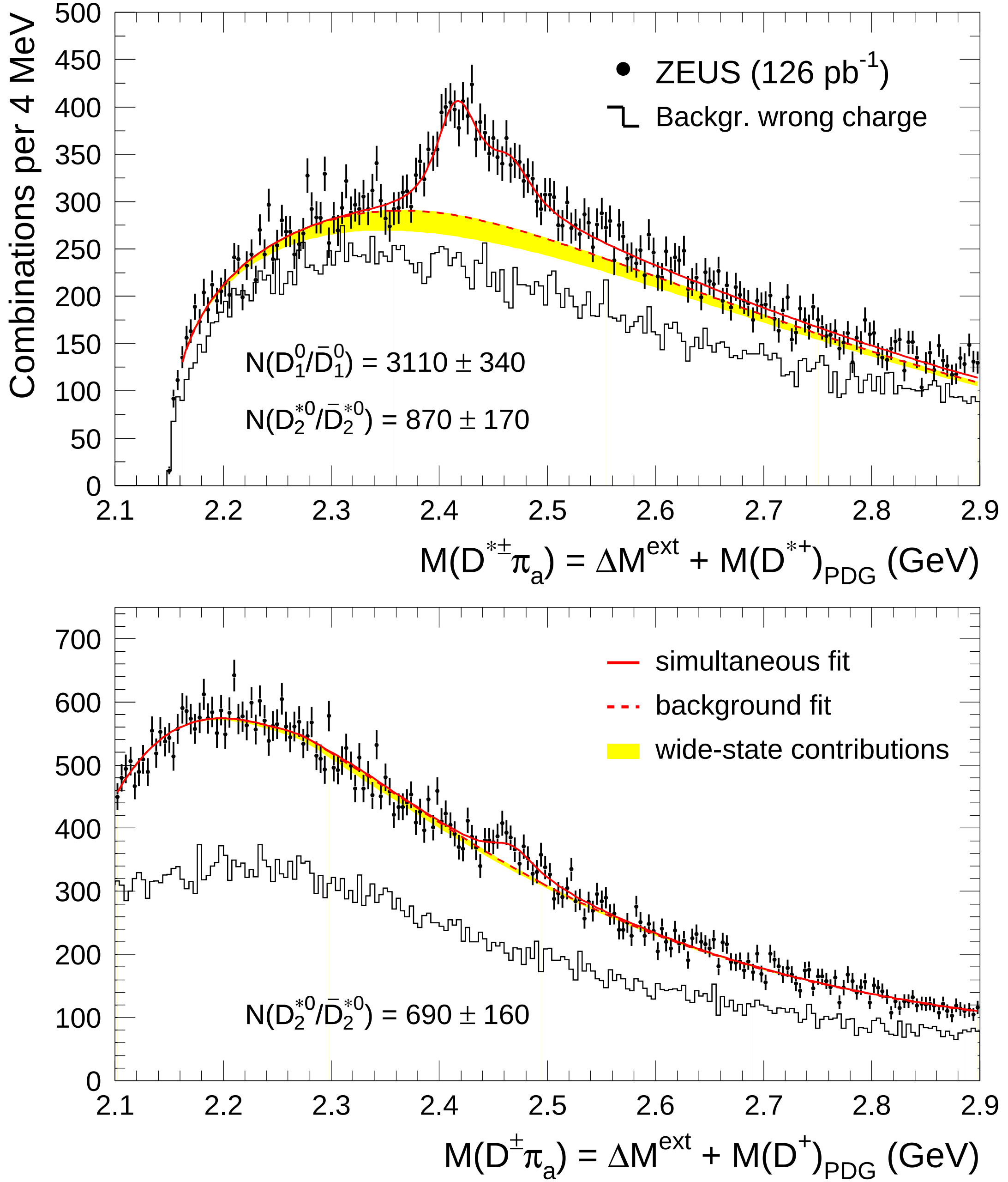
$D^+ \rightarrow K^- \pi^+ \pi^+$



$D^0 \rightarrow K^- \pi^+$



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



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

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

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

no access in wrong-charge distr.

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

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

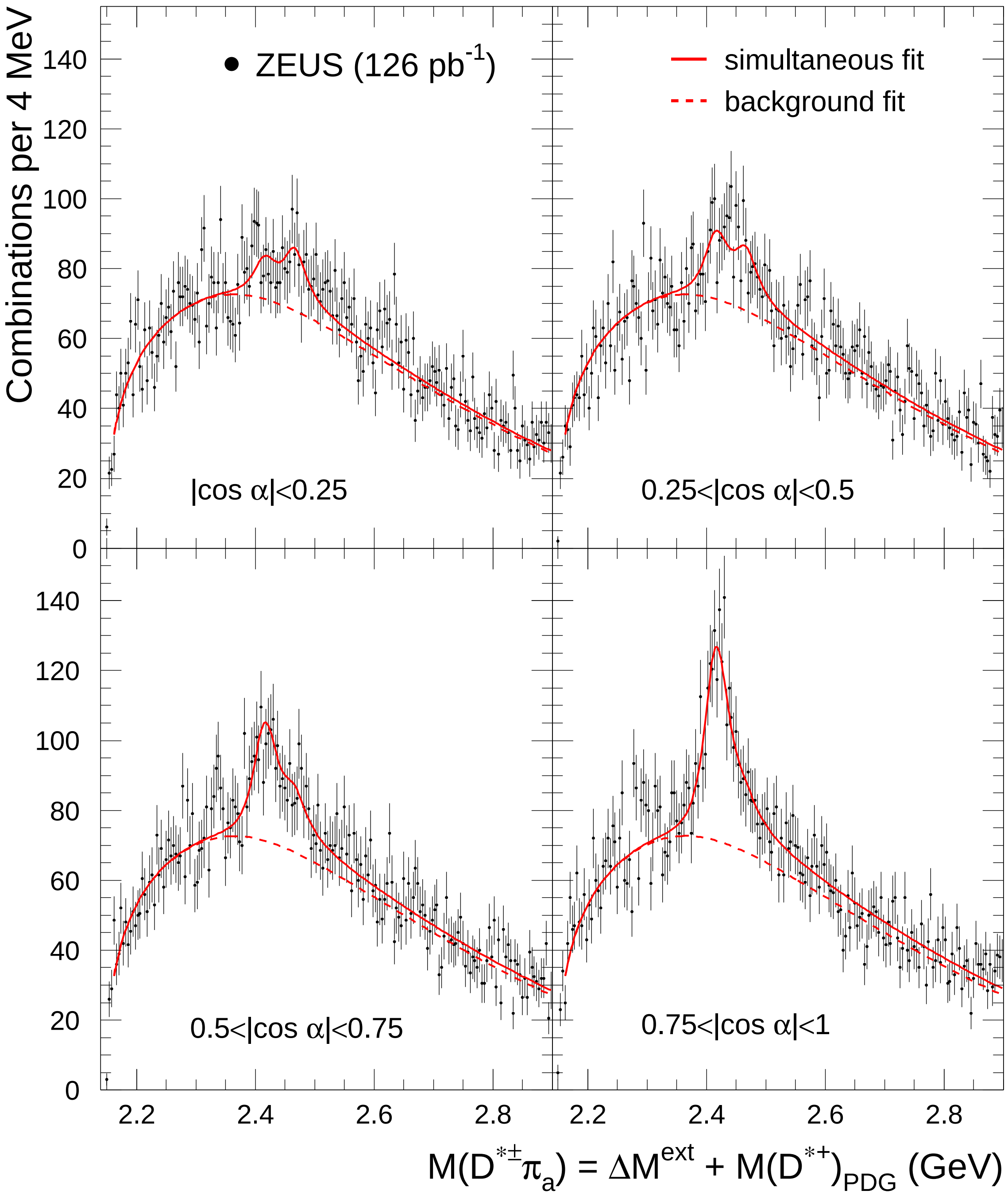
small access around 2460 MeV

no access in wrong-charge distr.

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

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

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

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

$\Longleftarrow$

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**

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

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

Width:

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

Helicity parameter:

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

Yields:

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

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

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

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

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

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

$$\frac{\mathcal{B}_{D_2^{*0}\to D^+\pi^-}}{\mathcal{B}_{D_2^{*0}\to D^{*+}\pi^-}} = 2.8 \pm 0.8(\text{stat.})^{+0.5}_{-0.6}(\text{syst.})$$

2.3 ± 0.6 (PDG 2006/8)

from isospin conservation:

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

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

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

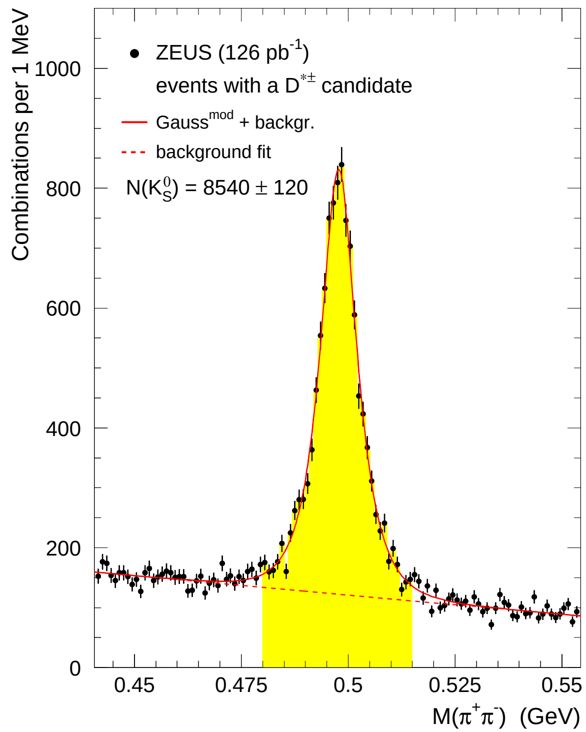
$$f(c \to D_1^0) = 3.5 \pm 0.4(\text{stat.})^{+0.4}_{-0.6}(\text{syst.})\ \%$$

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

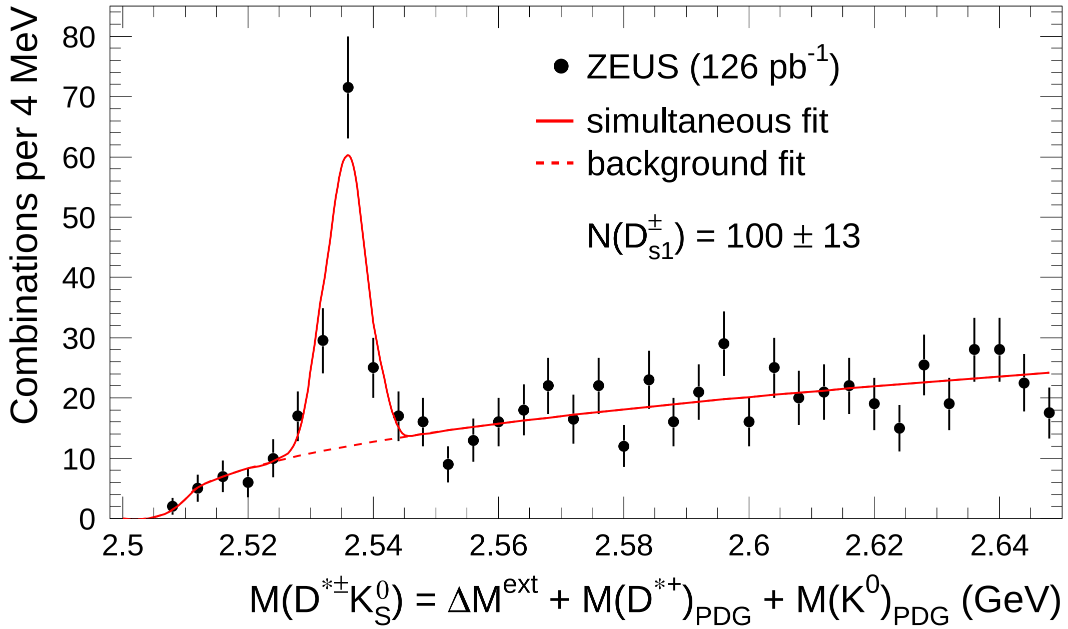
What about charm-strange excited D mesons ?

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

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



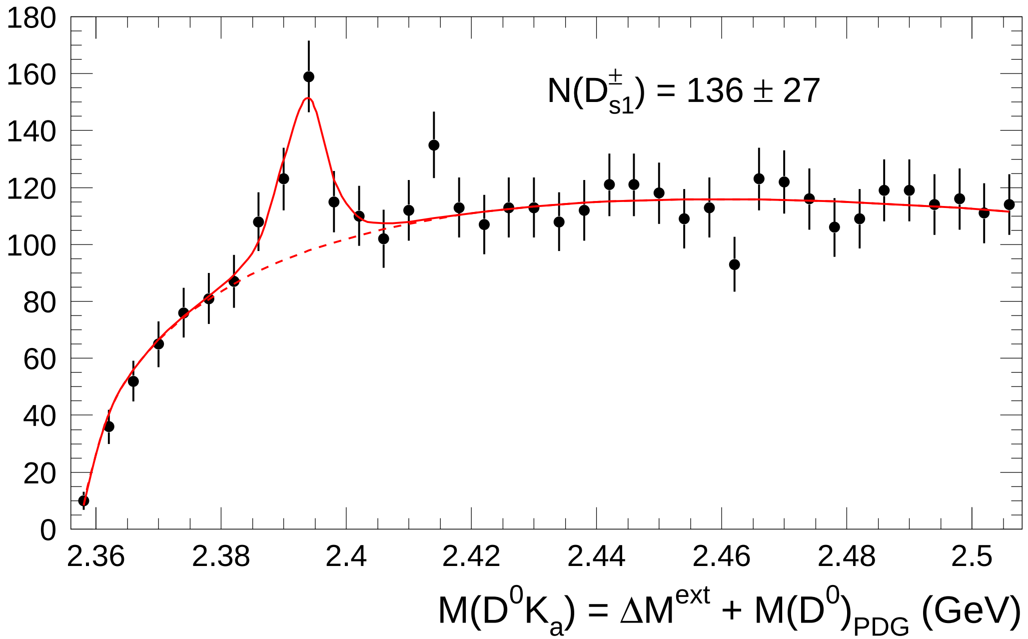
$M(D^{*+}K^0_s)$ and $M(D^0K^+)$ (+c.c.) distributions



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

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

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



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

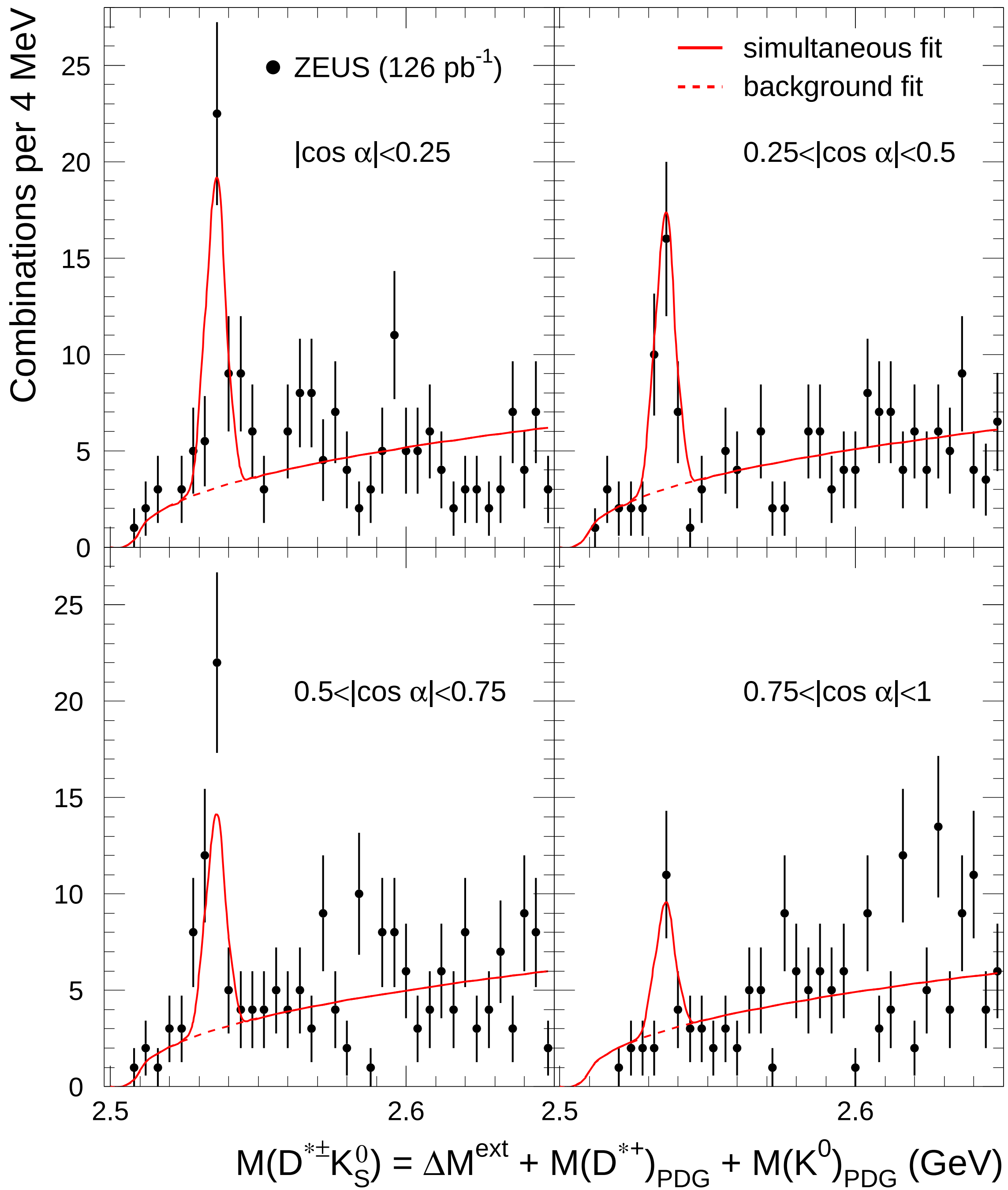
clear feed-down from $D^+_{s1} \to D^{*0}K^+$
(with $D^{*0} \to D^0\pi^0, D^0\gamma$)

shifted on 142.4 ± 0.2 MeV (MC)

can be described by
modified Gaussian (MC studies)

(no $D_{s2}(2573)^+ \to D^0K^+$ 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:

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

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

$h = -1$ for 1^-, 2^+

$\Longleftarrow$

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 $M(D^0K^+)$

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

$$N(D^+_{s1})_{D^{*+}K^0_s} = 100 \pm 13 \Longrightarrow \mathcal{F}_{D^+_{s1}\to D^{*+}K^0/D^{*+}} = 1.35 \pm 0.18 \pm 0.03\,\%$$

$$N(D^+_{s1})_{D^{*0}K^+} = 136 \pm 27 \Longrightarrow \mathcal{F}_{D^+_{s1}\to D^{*0}K^+/D^0_{\rm untag}} = 1.28 \pm 0.26 \pm 0.07\,\%$$

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

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

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

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

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

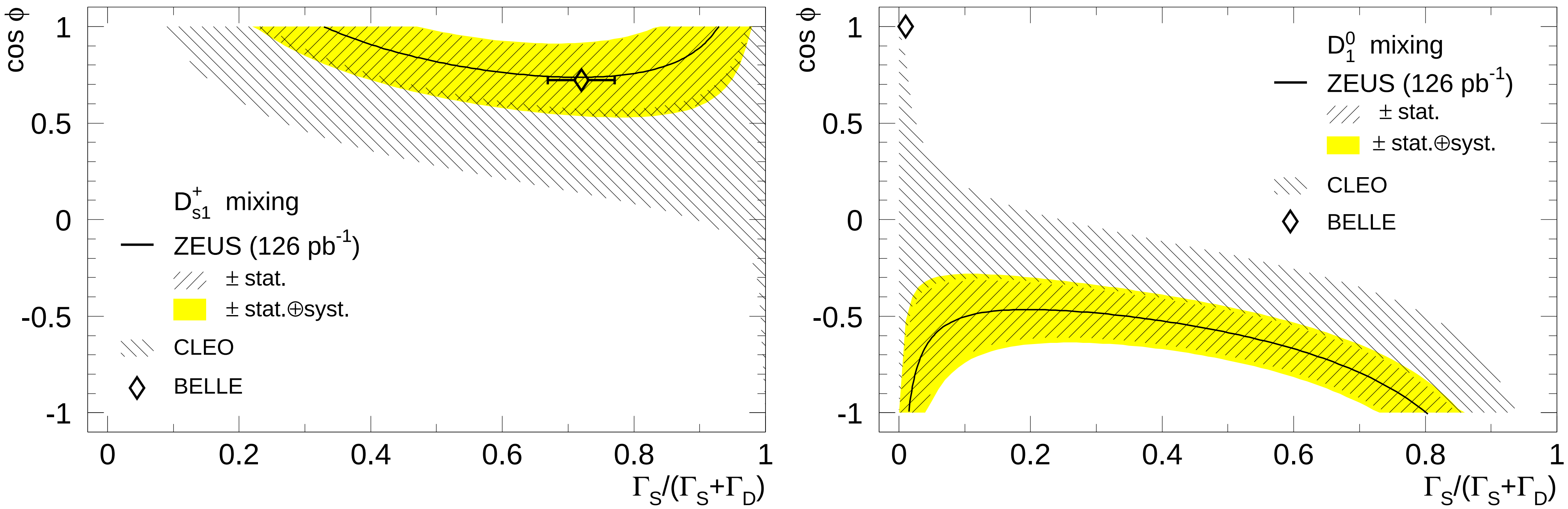
hardly consistent with $h = 0$, i.e. S-wave 1^+

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

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

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



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

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 $\Longrightarrow$ larger width

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

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

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

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

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

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

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

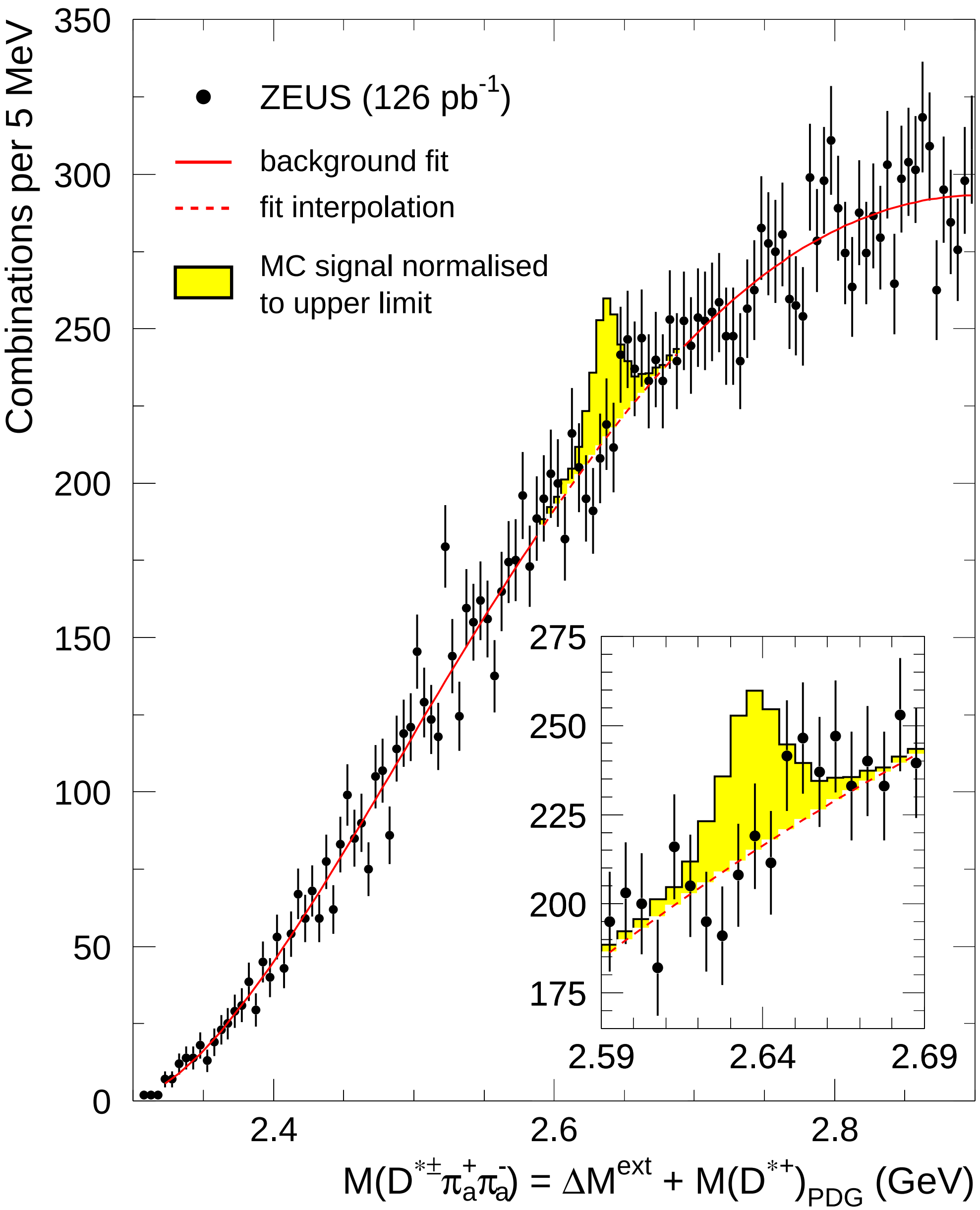
fragm. fractions for excited D mesons in ep and e^+e^- consistent

strangeness suppression for D_1 mesons:

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

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

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



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

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

no DELPHI's or other signals

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

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

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

stronger than the 0.9% OPAL limit

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

Summary

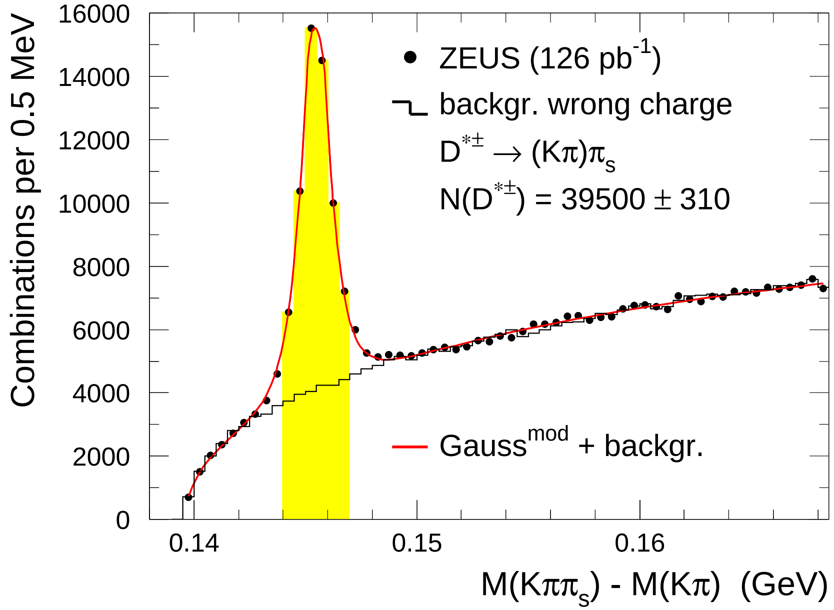
measurement of charm fragmentation function ($D^{*\pm}$) :

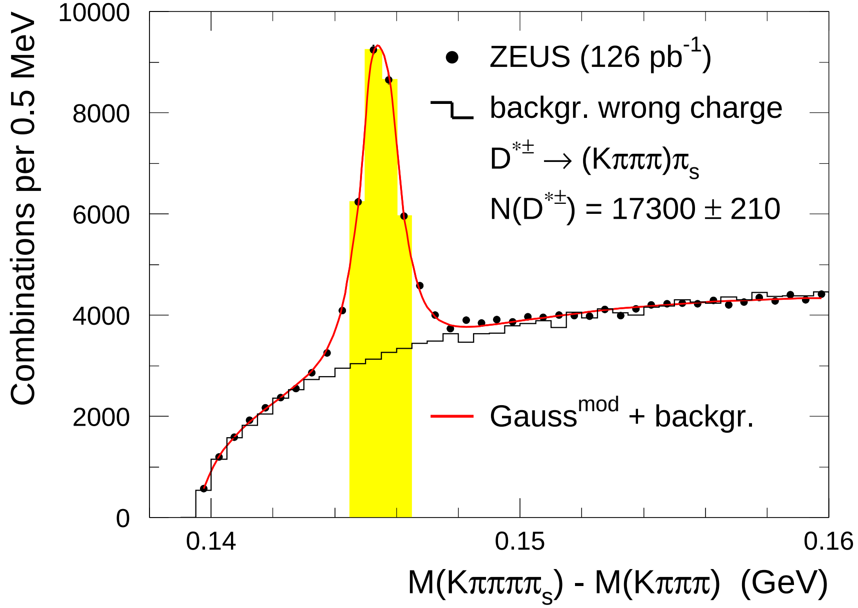
- clear signature of QCD scaling violation for $< z >$ in e^+e^- and ep data
- PYTHIA with Bowler and Peterson fragmentation functions provide good description; $\epsilon = 0.062 \pm 0.007^{+0.008}_{-0.004}$
- Peterson parameter for FMNR NLO ($0.079 \pm 0.008^{+0.010}_{-0.005}$) is larger than that (0.035) 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, $\gamma_s^{D_1} = 0.31 \pm 0.06^{+0.05}_{-0.04}$, agrees well with γ_s^D measured by ZEUS (and others) previously
- significant contrib. of both D- and S-wave amplit. to $D_{s1}^+ \to D^{*+}K_S^0$ decay
- $\Gamma(D_1^0)$ is larger than in prev. measurements (larger S-wave admixture ?)
- the strongest world limit: $f(c \to D^{*\prime +}) \cdot \mathcal{B}_{D^{*\prime +} \to D^{*+}\pi^+\pi^-} < 0.4\%$ (95% C.L.)

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





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

two D^* decay channels:

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

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

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

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

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

dE/dx : l_K =Prob(K) > 3%
l_π =Prob(π) > 1%

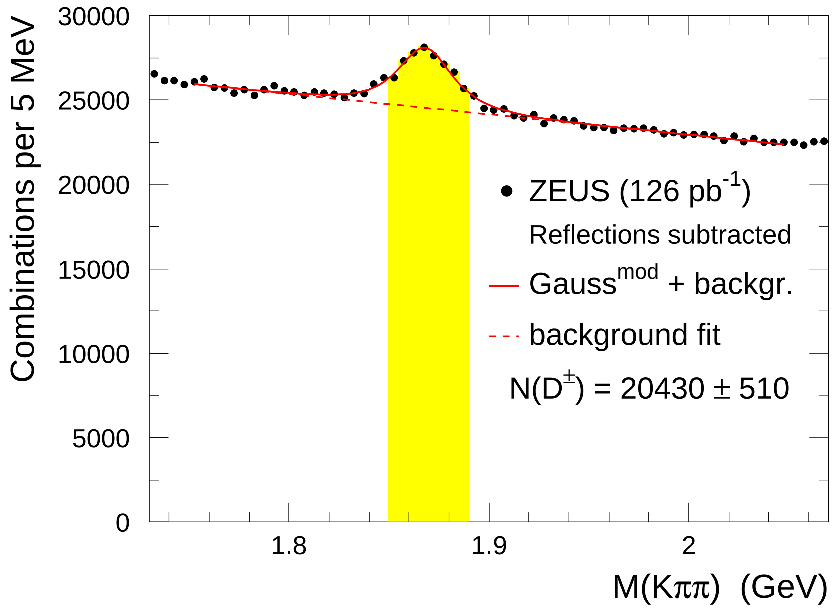
In the yellow bands after
after wrong-charge subtraction:

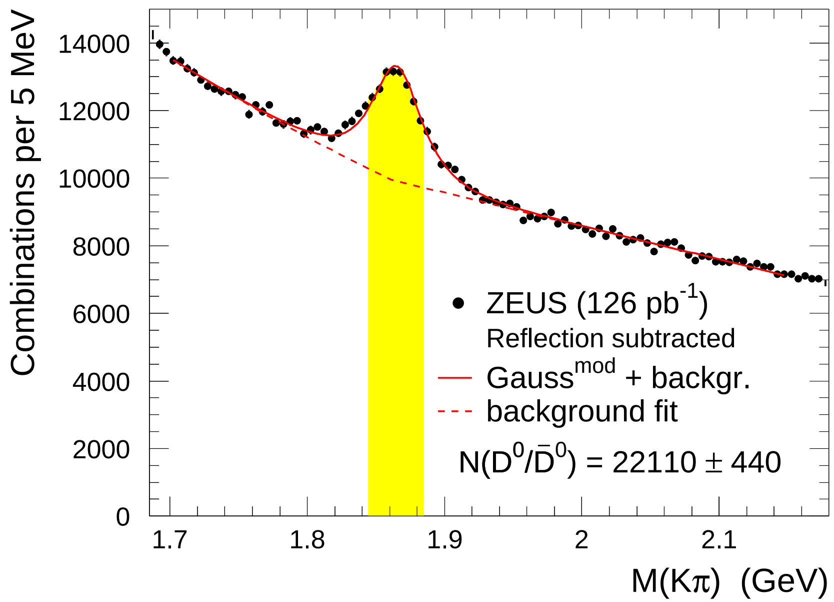
$$N(D^{*\pm}) \sim 56800$$

(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.)

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

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

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

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

$p_T(D^0) > 2.8$ 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.

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

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 $\sigma_{\rm res} = 5.6\,{\rm MeV}$ and $7.2\,{\rm MeV}$ 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 $\Longleftarrow$ small effect

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

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

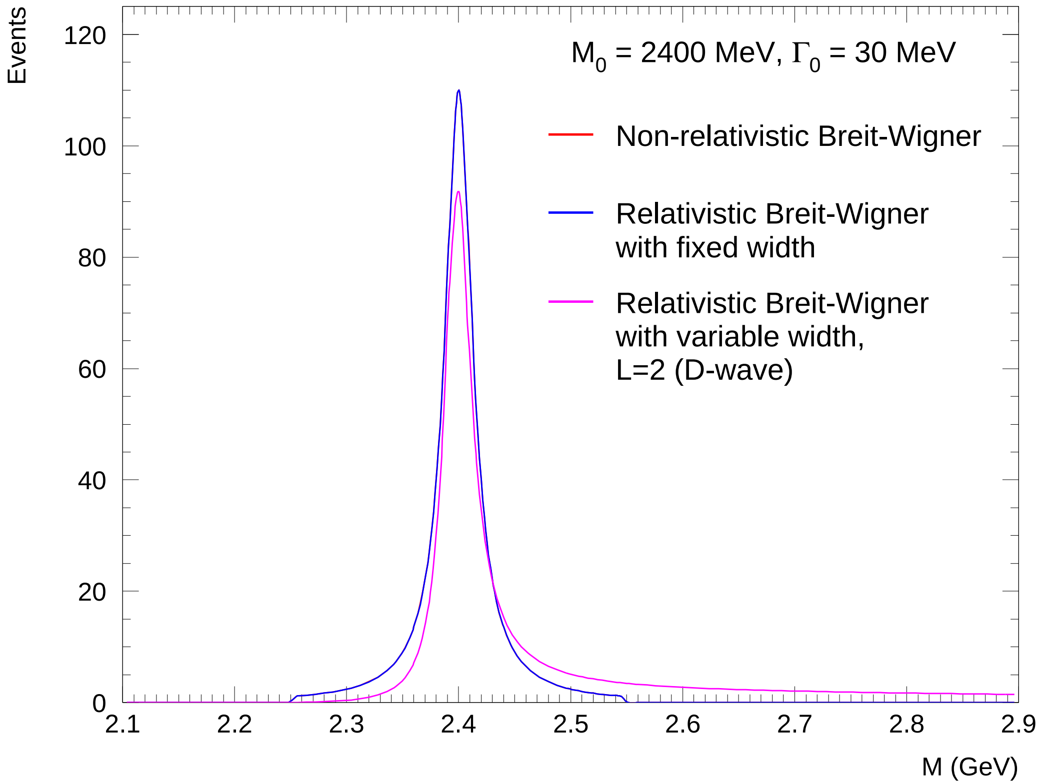
feed-downs from $D_1^0, D_2^{*0} \to D^{*+}\pi^-$ to $M(D^+\pi_a)$ were added to the fit function with relative yields taken from MC (7%) $\Longleftarrow$ small effect

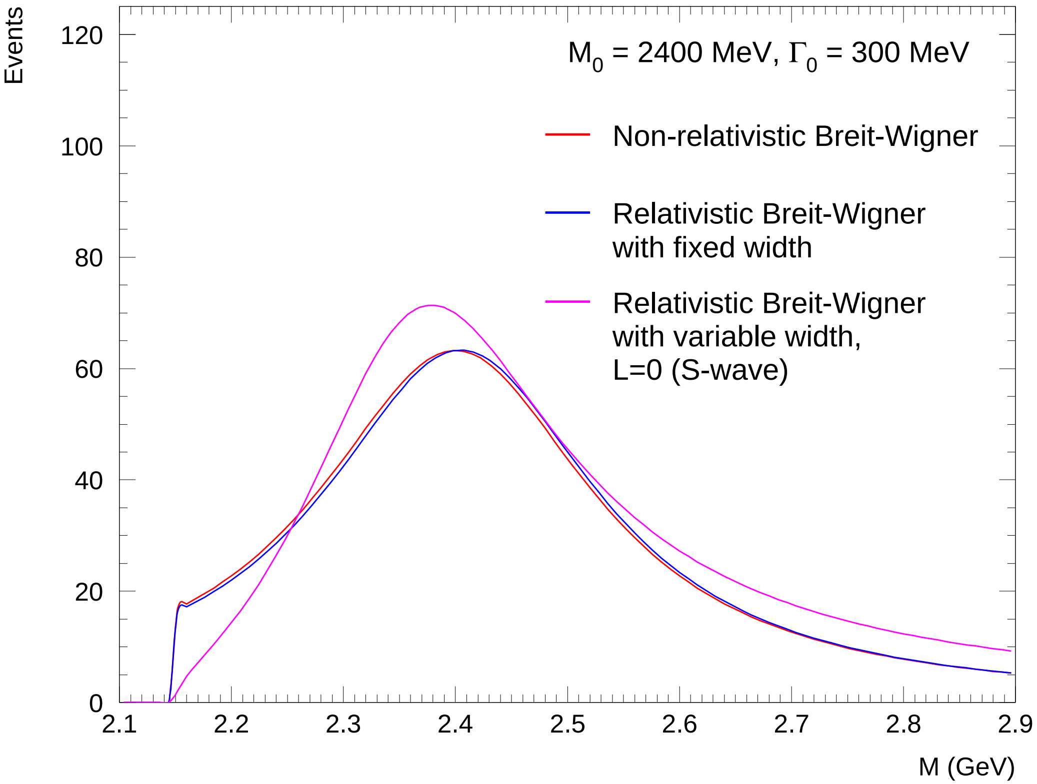
wide $D_1(2430)^0$ and $D_0^*(2400)^0$ states were added with the world average parameters
$D_1(2430)^0$ yield was set to that of the narrow $D_1(2420)^0$
$D_0^*(2400)^0$ yield was set to 1.7 of the $D_2^{*0} \to D^+\pi^-$ yield as observed by FOCUS
this rate, 1.7, is a sum of true $D_0^*(2400)^0$ and 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





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

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

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

D_1^0, D_2^{*0} fractions

corrected ratios (factors ~ 2)		extrap. to full phase space (~ 1.1 and ~ 1.2)
$\mathcal{F}_{D_1^0 \to D^{*+}\pi^-/D^{*+}}$	$= 10.4 \pm 1.2(\text{stat.})^{+0.9}_{-1.5}(\text{syst.})\ \%$	$11.6 \pm 1.3(\text{stat.})^{+1.1}_{-1.7}(\text{syst.})\ \%$
$\mathcal{F}_{D_2^{*0} \to D^{*+}\pi^-/D^{*+}}$	$= 3.0 \pm 0.6(\text{stat.}) \pm 0.2(\text{syst.})\ \%$	$3.3 \pm 0.6(\text{stat.}) \pm 0.2(\text{syst.})\ \%$
$\mathcal{F}_{D_2^{*0} \to D^{+}\pi^-/D^{+}}$	$= 7.3 \pm 1.7(\text{stat.})^{+0.8}_{-1.2}(\text{syst.})\ \%$	$8.6 \pm 2.0(\text{stat.})^{+1.1}_{-1.4}(\text{syst.})\ \%$

in full phase space:

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

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

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

re-writing 1st and solving 2 last equations:

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

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

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

D_{s1}^{+} fractions

corrected ratios (factors ~ 2) | **extrap. to full phase space (~ 1.2 and ~ 1.5)**

$\mathcal{F}_{D_{s1}^{+}\to D^{*+}K^{0}/D^{*+}} = 1.35 \pm 0.18(\text{stat.}) \pm 0.03(\text{syst.})\,\%$ $1.67 \pm 0.22(\text{stat.}) \pm 0.07(\text{syst.})\,\%$

$\mathcal{F}_{D_{s1}^{+}\to D^{*0}K^{+}/D^{0}_{\text{untag}}} = 1.28 \pm 0.26(\text{stat.}) \pm 0.07(\text{syst.})\,\%$ $1.93 \pm 0.40(\text{stat.})^{+0.12}_{-0.16}(\text{syst.})\,\%$

in full phase space:

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

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

solving system of 2 equations:

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

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