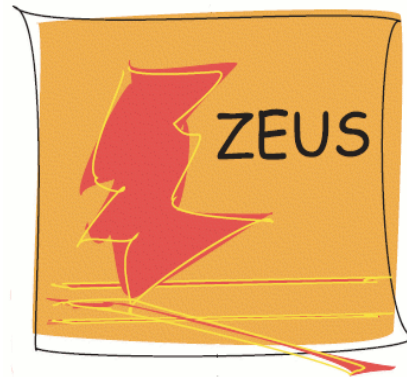


# Charm Fragmentation and Excited Charm Meson Production at HERA

ICHEP2010, July 23, Paris

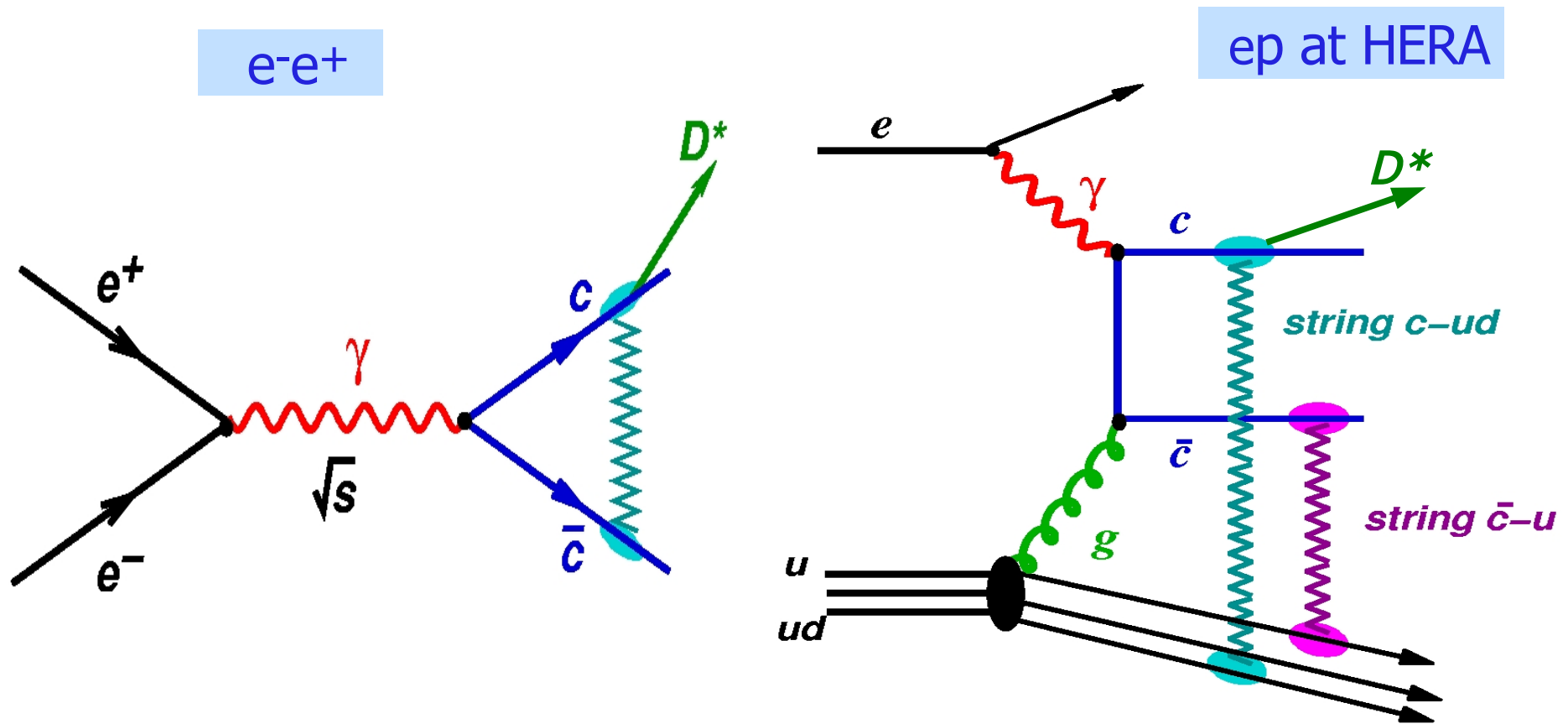
Olaf Behnke (DESY)

on behalf  
of



# 1. Charm Fragmentation: is it universal?

Observable  $z$ : Momentum fraction of  $c$  quark transferred to  $D^*$  meson



- Probe different colour configurations
- Study at HERA over wide  $p_T(c)$  range

# Phenomenological models:

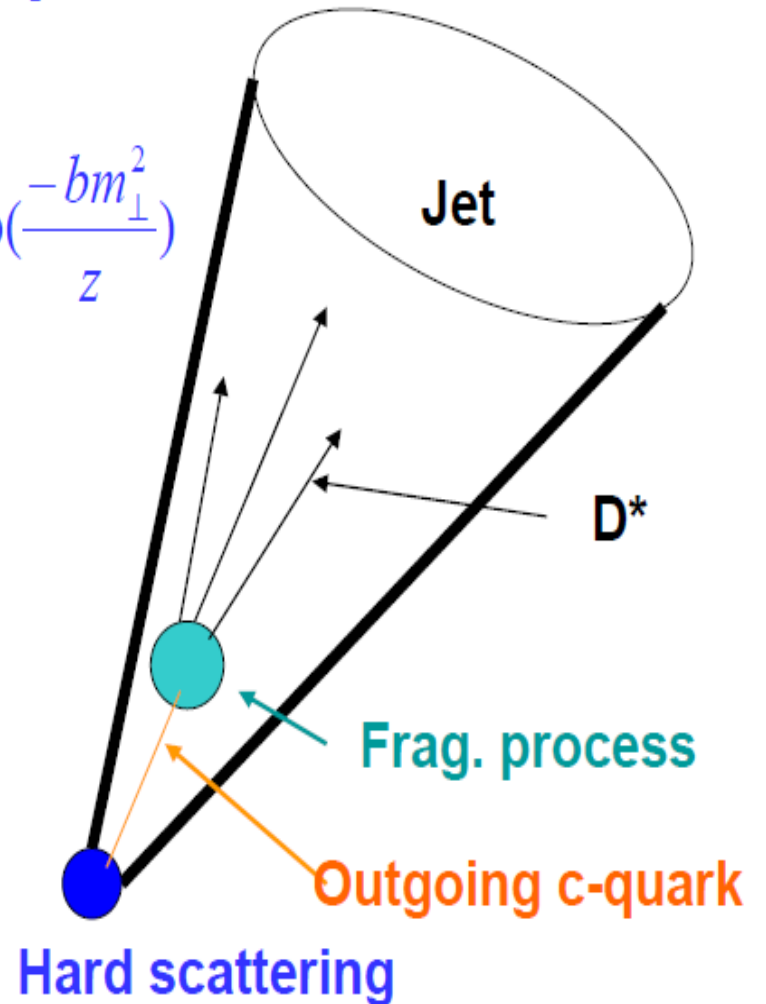
Peterson function:  $f(z) \propto \frac{1}{[z(1-1/z - \epsilon/(1-z))^2]}$

Kartvelishvili function:  $f(z) \propto z^\alpha (1-z)$

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

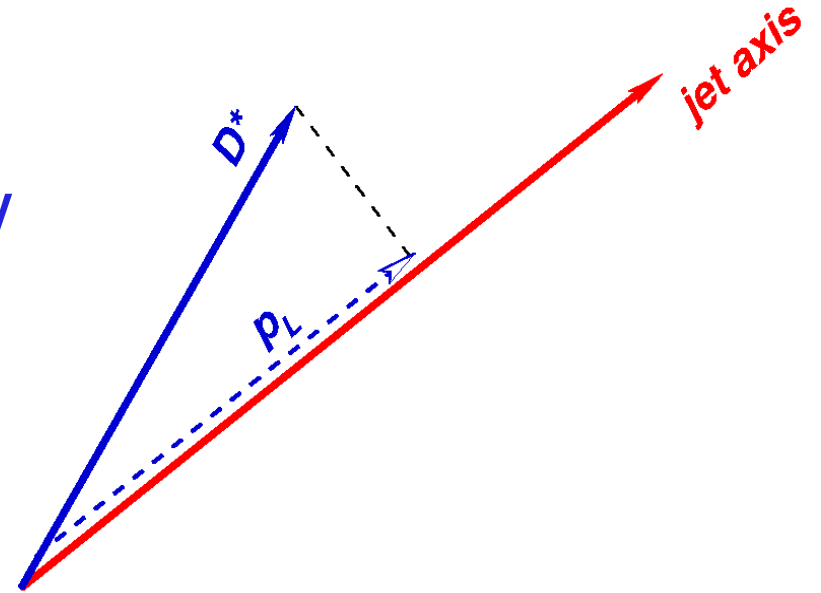
➤ Experimental definition  $e^+e^-$ :

$$z \sim E_{D^*} / E_{\text{beam}}$$

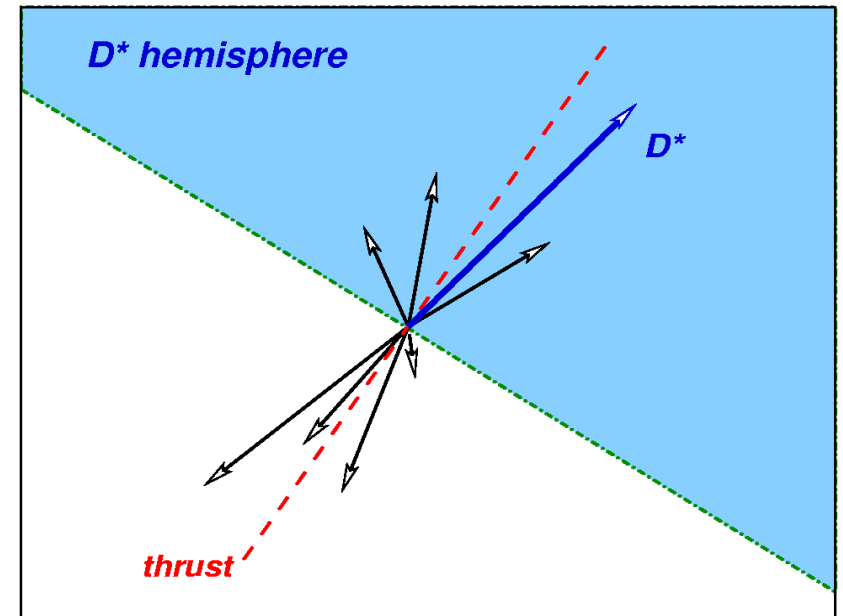


# Experimental definitions at HERA

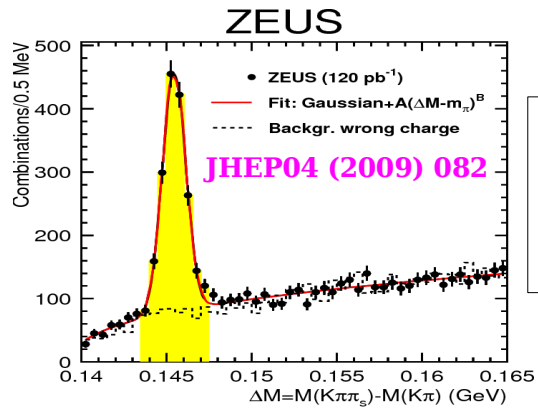
- Jet method (ZEUS, H1):  
energy of c-quark approximated by  
energy of reconstructed  $D^*$  jet  
$$z = (E + p_{||})_{D^*} / (E + p)_{\text{jet}}$$



- Hemisphere method (H1):  
energy of c-quark approximated  
by energy of reconstructed  
 $D^*$ -hemisphere  
$$z_{\text{hem}} = (E + p_{||})_{D^*} / \Sigma(E + p)_i$$

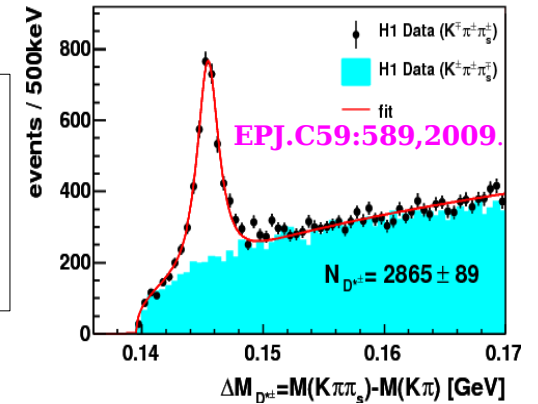


# Results and comparison with LO+PS+Jetset (standard tunes) MC simulations

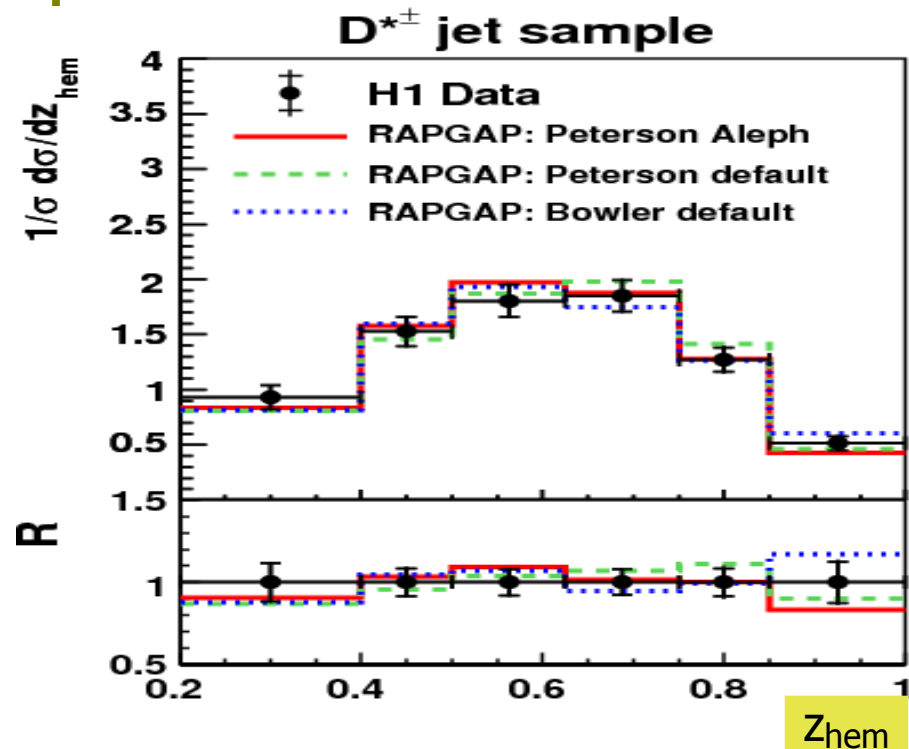
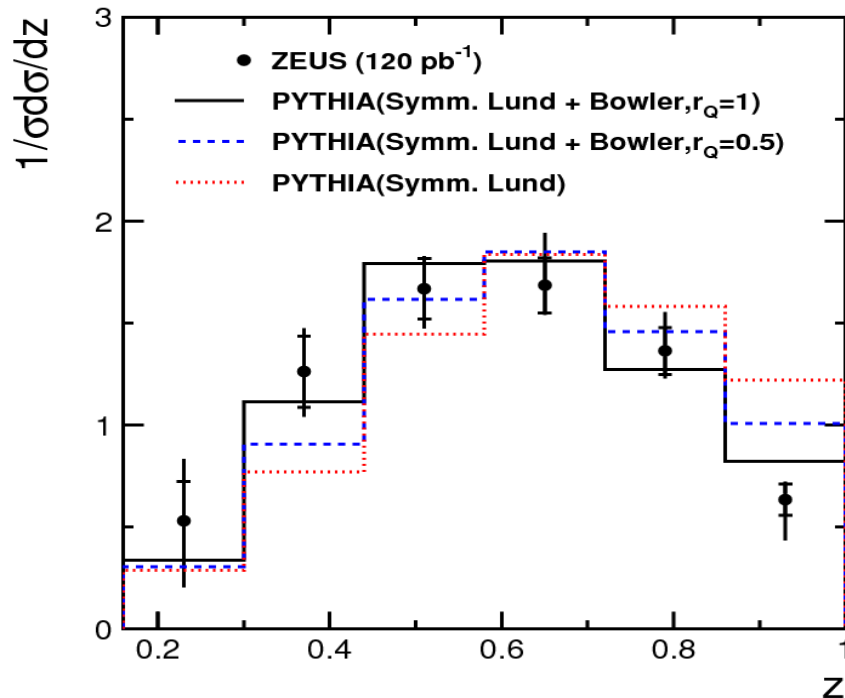


ZEUS:  
 $Q^2 < 1 \text{ GeV}^2$   
 $E_T(\text{jet}) > 9 \text{ GeV}$

H1:  
 $2 < Q^2 < 100 \text{ GeV}^2$   
 $D^*$  Jet sample:  $E_T(\text{jet}) > 3 \text{ GeV}$   
 No jet sample



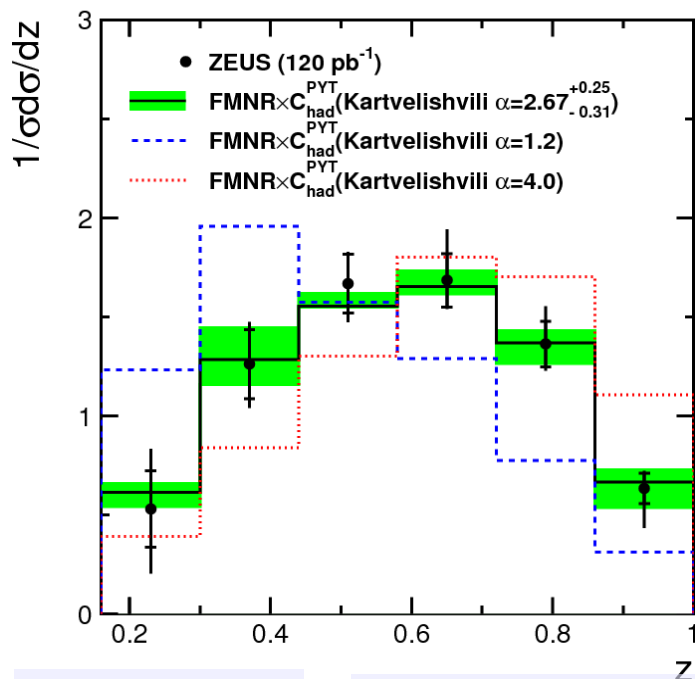
ZEUS



→ HERA results agree with MC models with fragmentation tuned to  $e^+e^-$  data ⇒ universality

# Results and Fits to NLO QCD

JHEP04 (2009) 082 ZEUS

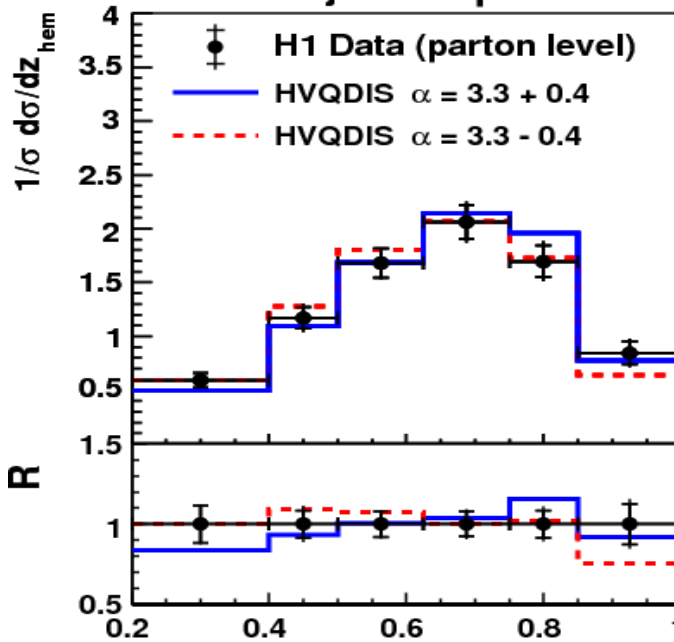


Alternative fits with Peterson FF

$$\epsilon = 0.079^{+0.013}_{-0.009}$$

EPJ.C59:589,2009.

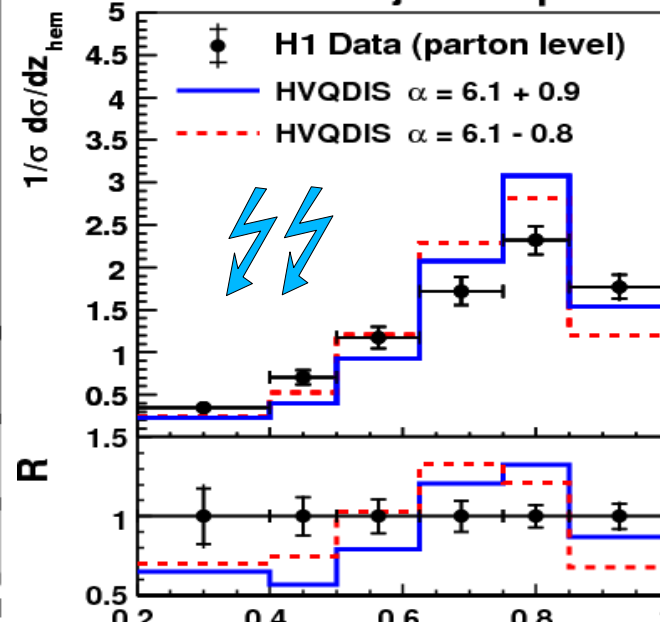
$D^{*\pm}$  jet sample



$$\epsilon = 0.068^{+0.015}_{-0.013}$$

Especially sensitive to kinematic threshold

No  $D^{*\pm}$  jet sample



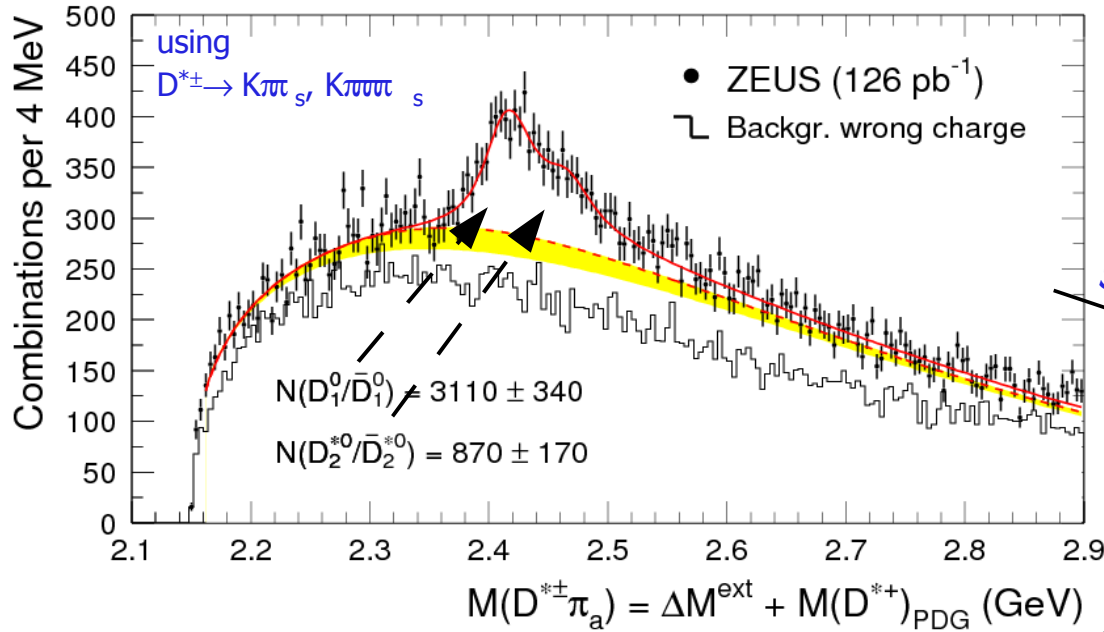
$$\epsilon = 0.007^{+0.001}_{-0.001}$$

Compare to typical value obtained from NLO fit to e+e- data:  $\epsilon = 0.035$  (Nucl.Phys.B565:245-266,2000)

- Jet samples vs NLO x Fragmentation functions:  $\Rightarrow$  fitted parameters somewhat different compared to parameters obtained from corresponding NLO fits to e<sup>+</sup>e<sup>-</sup> data (could be due to NLO being different/meaning different things for ep and ee)
- No D\* jet sample  $\Rightarrow$  results differ!  $\Rightarrow$  need refined theory treatment at charm production threshold!

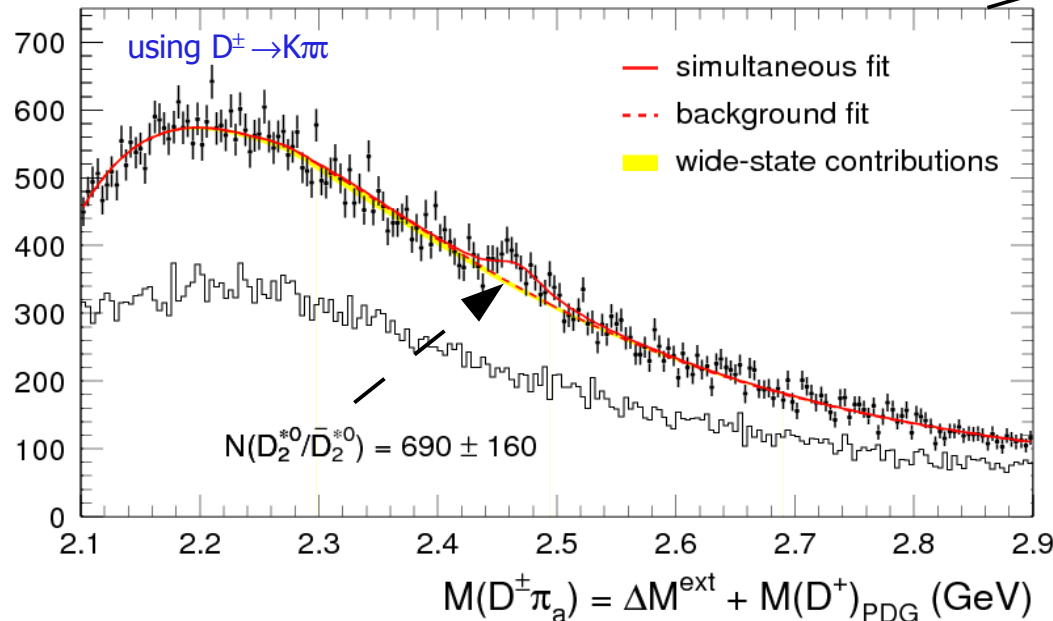


# M(D<sup>\*±</sup>π) and M(D<sup>±</sup>π) distributions in HERA I EPJ.C.60 (2009) 25-42



split signals in four helicity bins

Simultaneous fit

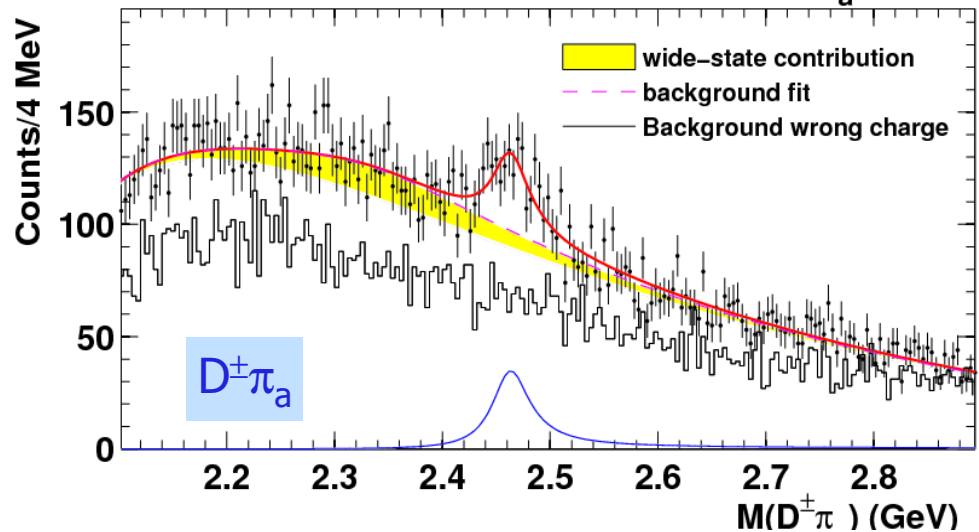
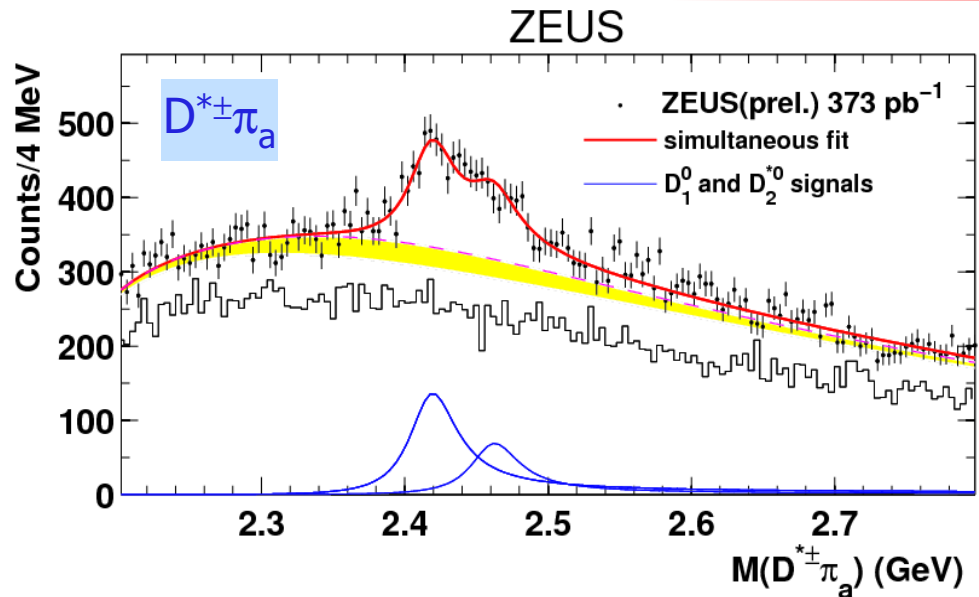
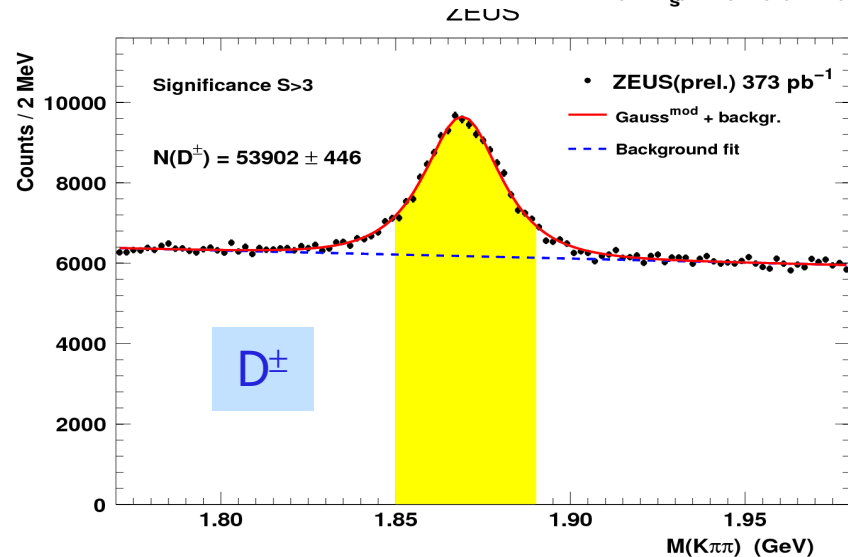
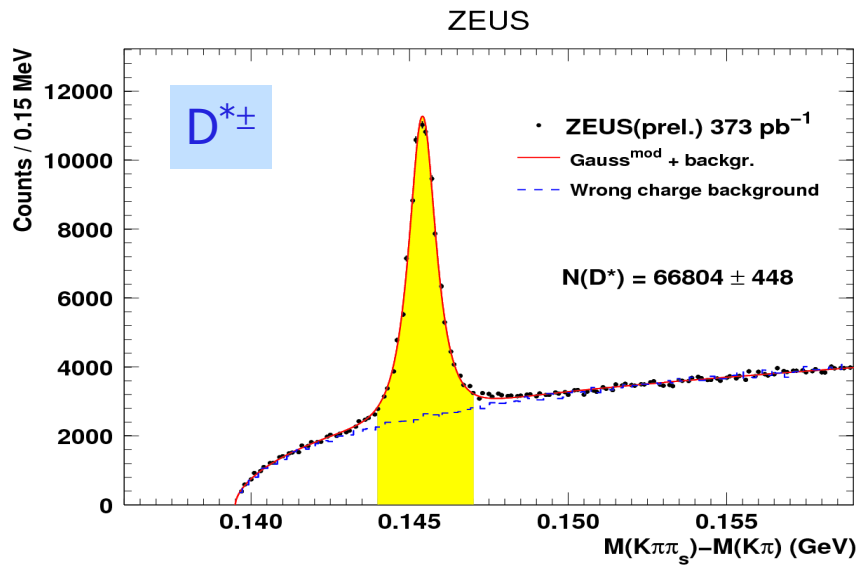


Fitted  $D_1(2420)^0$  mass and helicity parameters agree well with other measurements, but width  $\Gamma(D_1) = 53.2 \pm 7.1(\text{stat})^{+3.3}_{-4.9}(\text{syst.}) \text{ MeV}$  is higher than PDG average of  $20.4 \pm 1.7 \text{ MeV}$

→ Can we confirm with HERA II ?



# HERA II: Mass peaks ZEUS PREL.10-016

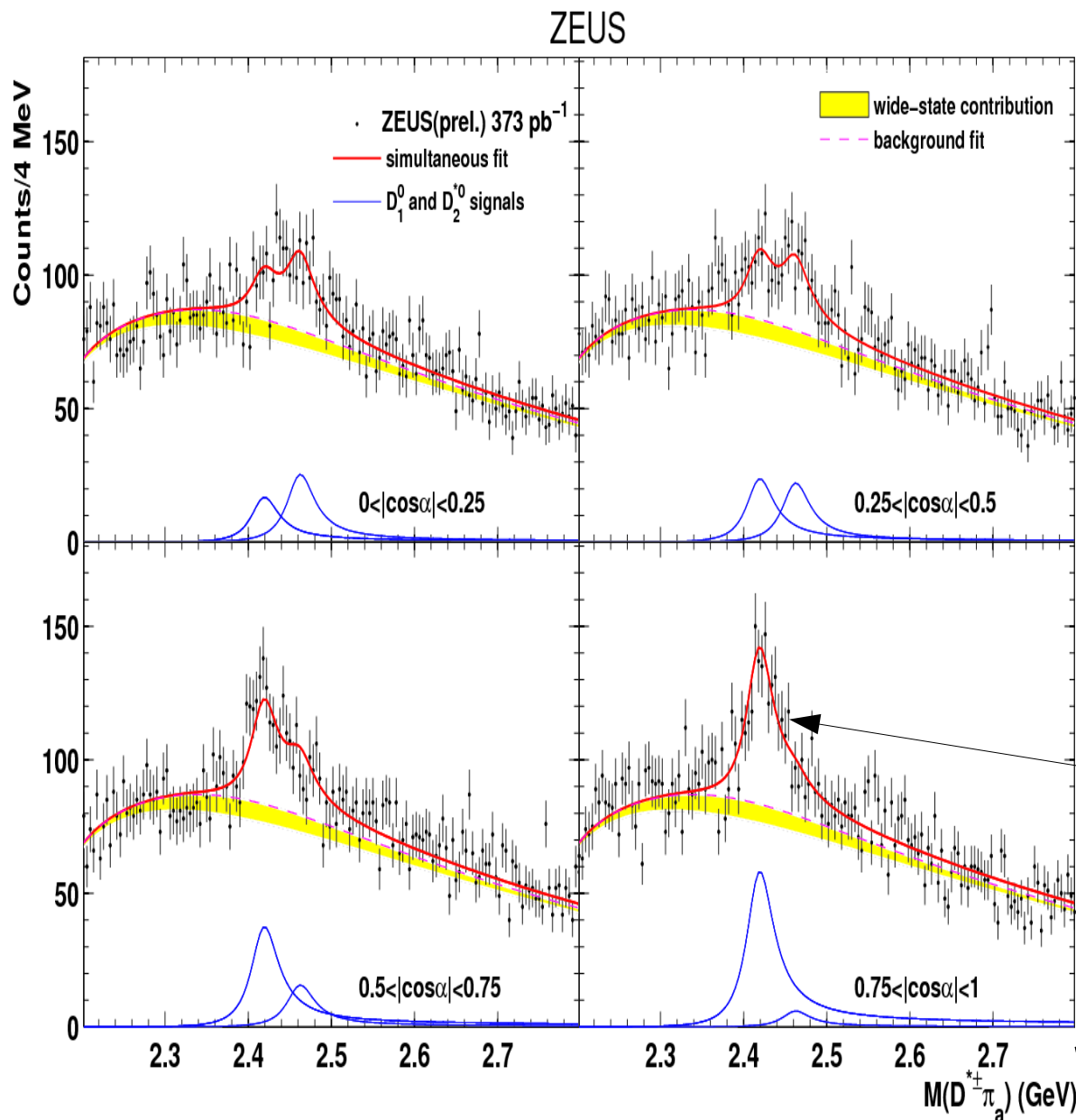


Improved  $D^\pm$  signal in HERA II  
with lifetime tag (Si-tracker)

→ Clear signals for  $D_1(2420)^0$  and  $D_2^*(2460)^0$   
→ Very well described by fit (described in the following)

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

ZEUS PREL.10-016



Helicity angle  $\alpha$  – between  $\pi_s$  and  $\pi_a$  in  $D^{*\pm}$  rest frame

$$dN/d\cos \alpha \sim 1 + h \cos^2 \alpha, h=?$$

HQET predicts:

$$h = 3 \text{ for } D_1(2420)^0$$

$$h = -1 \text{ for } D_2^*(2460)^0$$

$$h = 0 \text{ for } D_1(2430)^0$$

(wide state)

$D_1(2420)^0$  contributions increases with  $|\cos \alpha|$ , dominates bump for  $|\cos \alpha| > 0.75$

Make simultaneous  $\chi^2$  fit of these four and  $M(D^\pm\pi)$  histograms  
 fix ( $\Gamma(D_2^{*0}) = 43$  MeV and  $h(D_2^{*0}) = -1$ )

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

EPJ.C.60 (2009) 25-42

ZEUS PREL.10-016

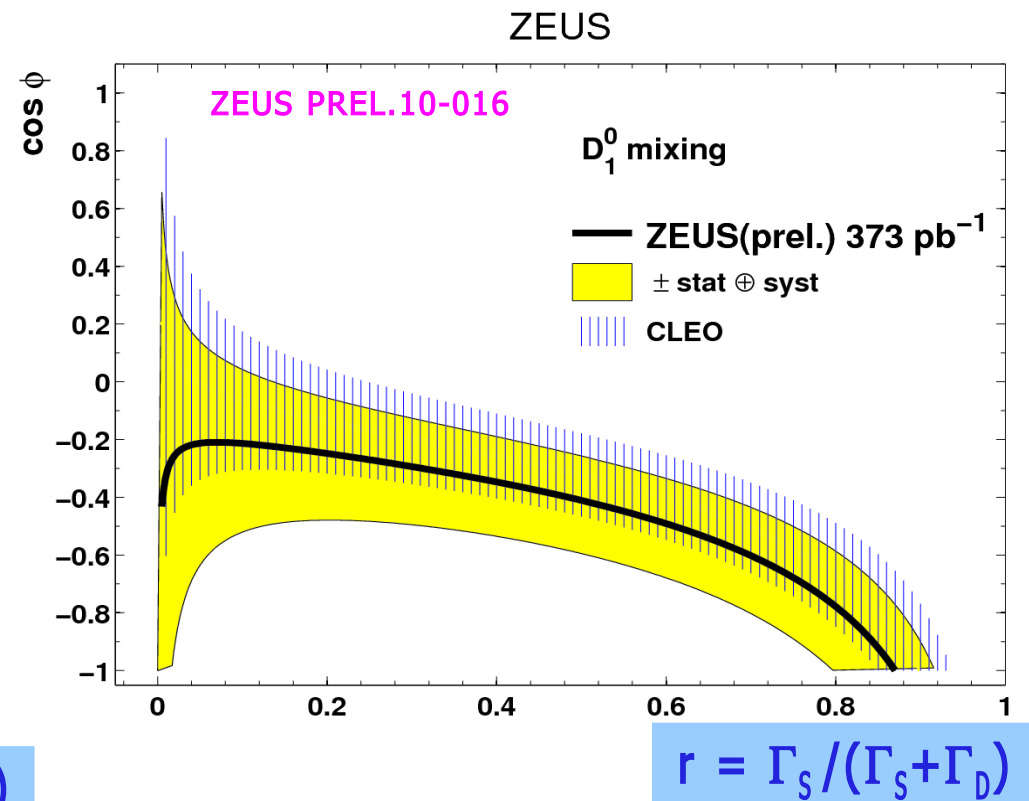
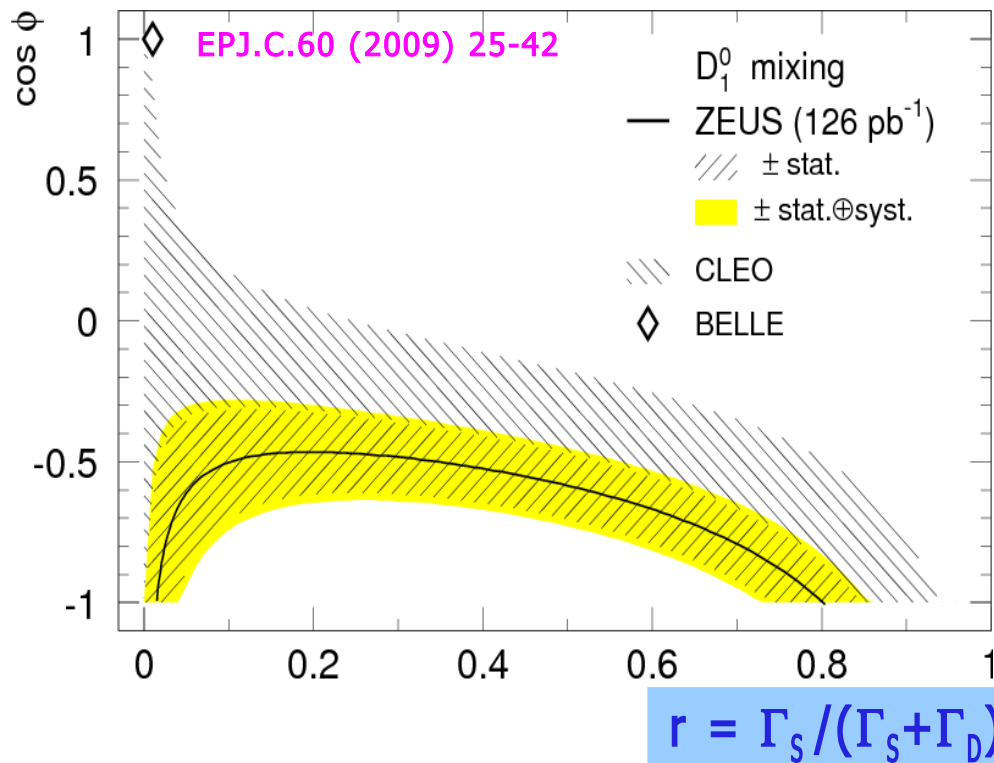
	HERA I	HERA II	PDG
$M(D_1^0)$ MeV	$2420.5 \pm 2.1 \pm 0.9$	$2422.2 \pm 1.7_{-2.8}^{+1.2}$	$2422.3 \pm 1.3$
$\Gamma(D_1^0)$ MeV	$53.2 \pm 7.2_{-4.9}^{+3.3}$	$43.4 \pm 6.2_{-10.4}^{+7.3}$	$20.4 \pm 1.7$
$h(D_1^0)$	$5.9_{-1.7-1.0}^{+3.0+2.4}$	$3.5_{-1.0-0.8}^{+1.6+2.0}$	
$M(D_2^{*0})$ MeV	$2469.1 \pm 3.7_{-1.3}^{+1.2}$	$2465.0 \pm 3.3_{-2.9}^{+1.2}$	$2461.1 \pm 1.6$
$\Gamma(D_2^{*0})$ MeV	43 fixed	43 fixed	$43 \pm 4$
$h(D_2^{*0})$	-1 fixed	-1 fixed	

- HERA II prel. results confirm HERA I:
- Masses  $M(D_1^0), M(D_2^{*0})$ : agree with PDG2008 values
- Helicity parameter  $h(D_1^0)$ :
  - inconsistent with pure S-wave decay,  $h=0$
  - Consistent with HQET prediction for a pure D-wave decay,  $h=3$
- Width  $\Gamma(D_1(2420)^0)$ : significantly above PDG2008 value
  - ⇒ One possible explanation: larger s-wave admixture at ZEUS with respect to that in measurements with restricted phase space (e.g. Belle)

# Mixing of D- and S-waves for $D_1(2420)^0$

Relative phase  $\phi$  between D and S wave amplitudes can be expressed for given ratio of partial widths  $r = \Gamma_S/(\Gamma_S+\Gamma_D)$  as function of measured helicity  $h$

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




→ ZEUS measurements favour negative  $\cos \phi$

# Conclusion

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## 1. Measurements of charm fragmentation function ( $D^{*\pm}$ ) at HERA:

- For events with hard scale: results & parameters  $\sim$ consistent with  $e^-e^+$  data  
⇒ Fragmentation 
- For events at kinematic threshold: ⇒ results & parameters differ,  
poor description by NLO QCD + standard fragmentation functions  
⇒ need for refined theory description

## 2. Excited charm mesons at HERA

- New HERA II results on  $D_1(2420)^0$  and  $D_2^*(2460)^0$  consistent with HERA I
- $\Gamma(D_1^0)$  is larger than in measurements at other colliders/environments  
(larger S-wave admixture?)