Charm Fragmentation Function

Zuzana Rúriková

HERA LHC Workshop – June 7, 2006

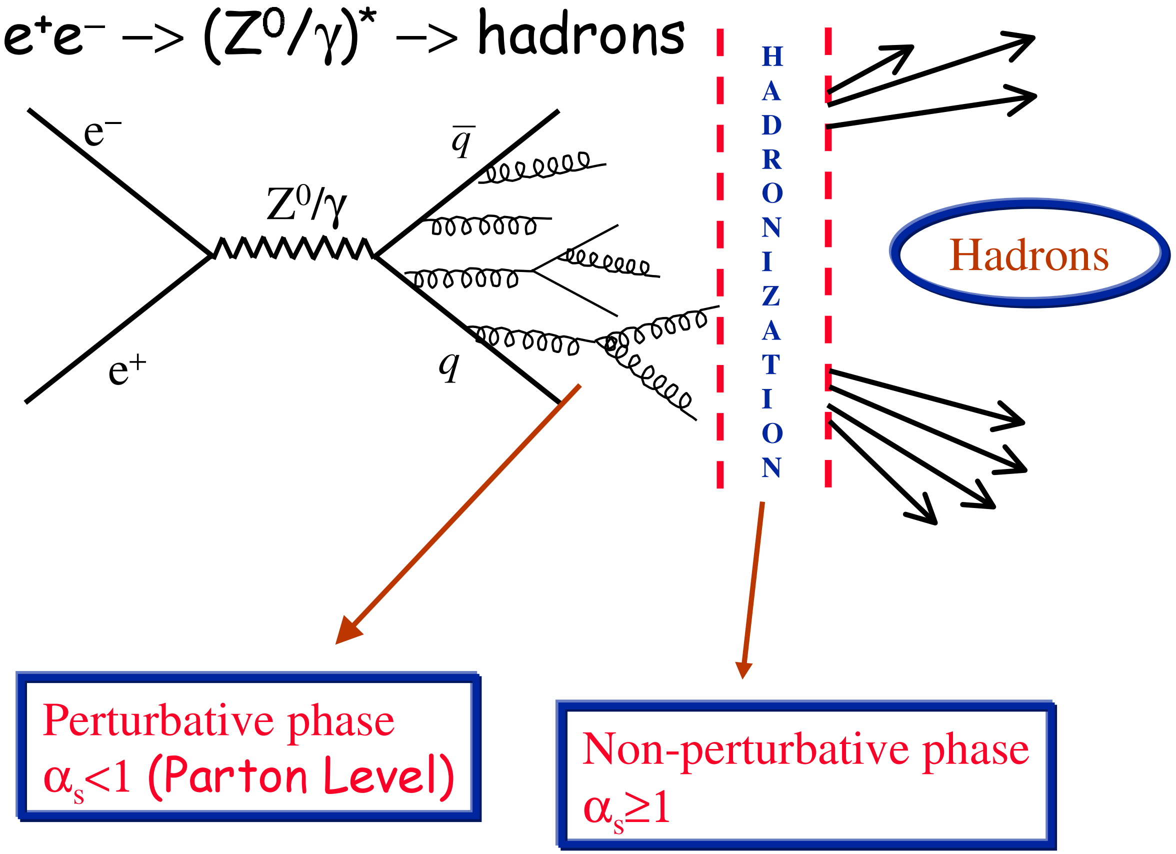
- **Introduction**
- e^+e^- **experimental results**
- ep **experimental results**
- **How to test universality?**

Motivation

Charmed hadrons, i.e. D^*, $D^\pm$, ... often used for tagging of charm events.

In order to extract information about **underlying physics** one needs to know more about the **non-perturbative part of the process**:

- **Fragmentation fractions**
- **Fragmentation functions**



$e^+e^- \rightarrow (Z^0/\gamma)^* \rightarrow$ hadrons

Perturbative phase
$\alpha_s<1$ (Parton Level)

Non-perturbative phase
$\alpha_s \geq 1$

Factorization

- **cross section for process $pp \to H + X$:**

$$\sigma_H = \sum_{i,j} f_{i/p}(x_1, \mu_f) \otimes f_{j/p}(x_2, \mu_f) \otimes \hat{\sigma}_{ij\to cX}(\alpha_s(\mu_r), \mu_r, \mu_f) \otimes D_c^H(z, \mu_f)$$

Parton Density Function

Hard Scattering (perturbative)

Fragmentation Function

$\Longrightarrow$ **non-perturbative FF depends strongly on the choice of perturbative description (LO, NLO, NLL, ... or LO+PS Monte Carlo)**

- **hence one should be careful and use them consistently**
  (including scale values, and parameter settings)

- ignoring this fact can cause serious problems (e.g. discrepancy between data and theory for beauty X-sections at TEVATRON of factor 2-3)

Fragmentation Issues

Fragmentation Function (FF):

provides information about the energy fraction which is transfered from quark to a given meson (the larger m_Q the harder the fragmentation function)

Questions to be answered:

▷ what's the **proper parametrization** of non-perturbative frag. function?

- Peterson: $f(z) \propto 1/[z(1-\frac{1}{z}-\frac{\varepsilon}{(1-z)})^2]$
- Kartvelishvili: $f(z) \propto z^{\alpha}(1-z)$
- Lund symmetric: $f(z) \propto \frac{1}{z}(1-z)^a \exp(-\frac{bm_t^2}{z})$
- Bowler: $f(z) \propto \frac{1}{z^{1+r_b m_t^2}}(1-z)^a \exp(-\frac{bm_t^2}{z})$

▷ is fragmentation function **universal**?
(i.e. are FF portable from e^+e^- to ep and pp?)

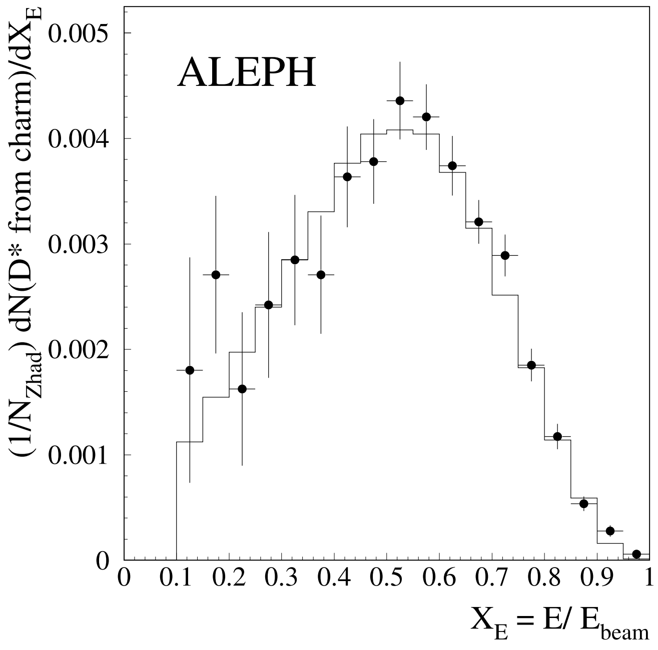
Charm Fragmentation Function Measurements in e^+e^-

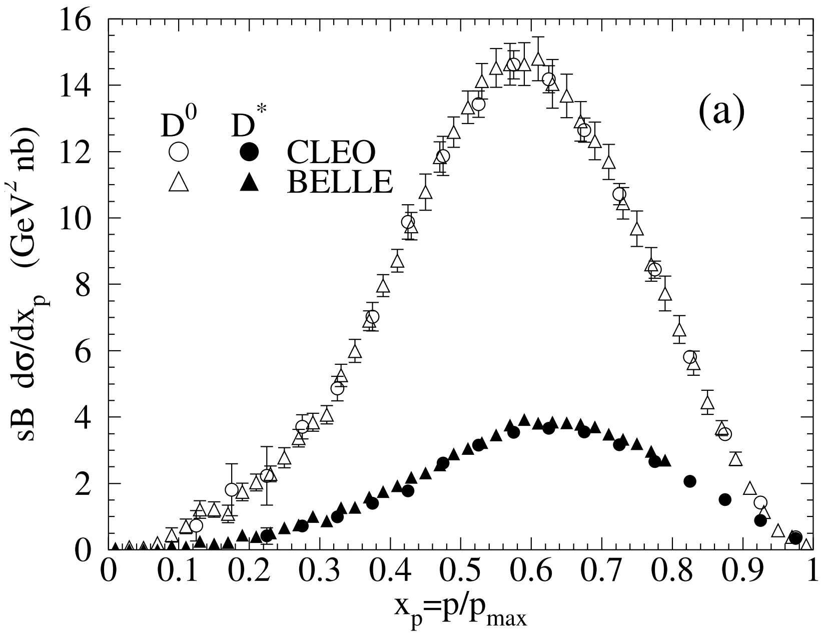
▷ $FF(c \to D)$ **measured in terms of x observables:**

- $x = E_D/E_{\text{beam}}$ at large $\sqrt{s}$
- $x = p_D/p_{\max}$ at small $\sqrt{s}$, where $p_{\max} = \sqrt{E^2_{\text{beam}} - m^2_D}$

ALEPH measurement at Z^0 resonance ($\sqrt{s} = 91.2$ GeV).

Recent precise measurements from CLEO and BELLE near the $\Upsilon(4S)$ ($\sqrt{s} = 10.6$ GeV).





Extracted FF for Monte Carlo

- **JETSET/PYTHIA:** LO +PS Monte Carlo with Lund string fragmentation model
- $FF_{\rm np}$ obtained from χ^2 fit to $d\sigma/dx$ distribution
- **quantitative picture of BELLE analysis for $FF(c \to D^*)$:**

Bowler:	$\chi^2/N_{DF} = 541.8/55$
Lund symmetric:	$\chi^2/N_{DF} = 965.6/55$
Kartvelishvili:	$\chi^2/N_{DF} = 1271.1/54$
Collins-Spiller:	$\chi^2/N_{DF} = 1540.7/54$
Peterson:	$\chi^2/N_{DF} = 3003.0/54$

Bowler parametrization with two free parameters provides best description of data, but in general for all cases χ^2 is very bad.

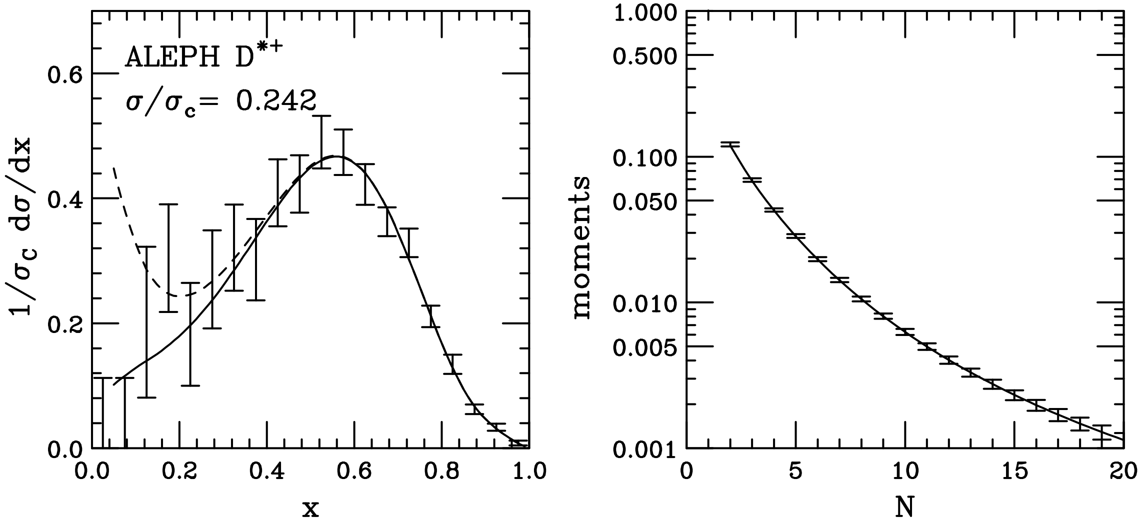
Extracted FF for NLO+NLL+soft gluon Resummation I.

- Fits of non-perturbative FF performed in **Mellin moment space**:

$$\widetilde{FF}(N) = \int_0^1 x^{N-1} FF(x)dx$$

- **Advantage:** Mellin transform turns convolution into simple product

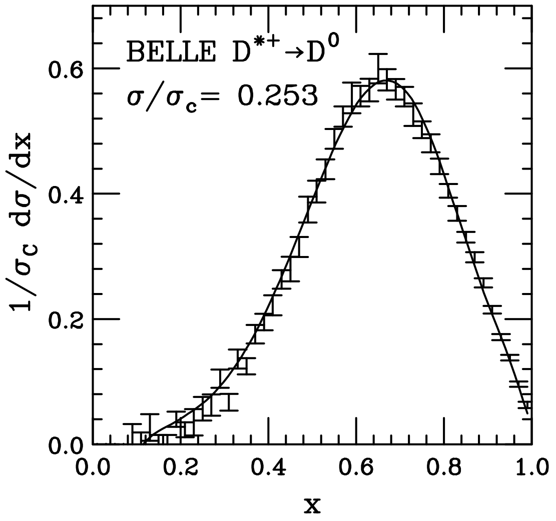
$$FF(x) = FF_{\mathrm{pert}} \otimes FF_{\mathrm{np}}(x) \quad \rightarrow \quad \widetilde{FF}(N) = \widetilde{FF}_{\mathrm{pert}}(N) \times \widetilde{FF}_{\mathrm{np}}(N)$$

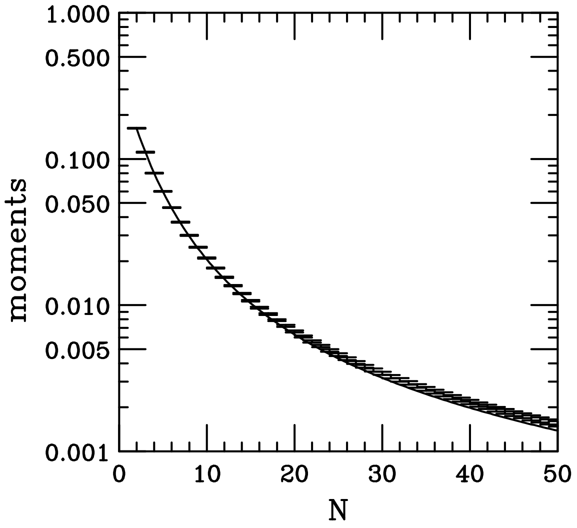


Fit to ALEPH data

(Cacciari, Nason, Oleari)

Extracted FF for NLL+soft gluon Resummation II.





Fit to BELLE data

(Cacciari, Nason, Oleari)

- ▷ **Fitted parametrization:** $f(x) \propto \delta(1-x) + \frac{c}{N_{a,b}}(1-x)^a x^b$
- ▷ **ALEPH:** a= 2.4±1.2, b=13.9±5.7, c=5.9±1.7
- ▷ **CLEO/BELLE:** a= 1.8±0.2, b=11.3±0.6, c=2.46±0.07

Fits not in agreement! Does universality of $\mathrm{FF}_{\mathrm{np}}$ not hold?

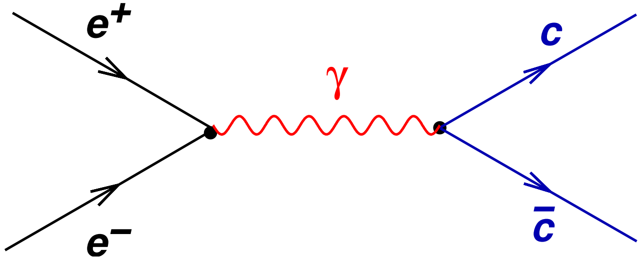
From e^+e^- to ep Collisions

e^+e^- collisions

- ▷ natural choice:

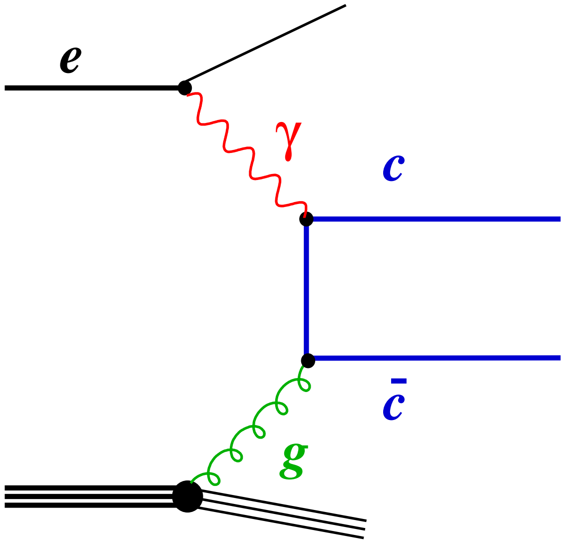
$$z = \frac{E_{D^*}}{\sqrt{s}/2} = \frac{E_{D^*}}{E_{\text{beam}}}$$

- ▷ assuming LO processes - direct measurement of non-perturbative fragmentation function



ep collisions

- ▷ energy of c-quark unknown $\Longrightarrow$ choice of z observable not so obvious
- ▷ differences: IPS contribution,
  different color flow



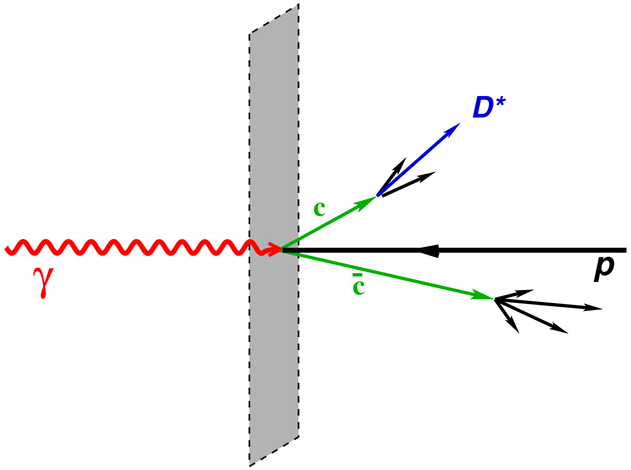
Definitions of Fragmentation Observables in ep

Jet method:

- ▷ momentum of c-quark approximated by momentum of rec. D^*-jet

$$\mathrm{z_{jet}} = \frac{(E+p_\mathrm{L})_{D^*}}{(E+p)_\mathrm{jet}}$$

- ▷ $k_\perp$-clus jet algorithm applied

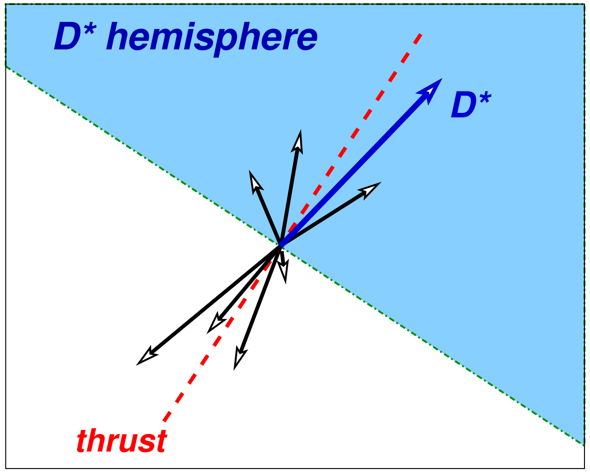


Hemisphere method:

- ▷ momentum of c-quark approximated by momentum of rec. D^*-hemisphere

$$\mathrm{z_{hem}} = \frac{(E+p_\mathrm{L})_{D^*}}{\sum_\mathrm{hem}(E+p)_i}$$

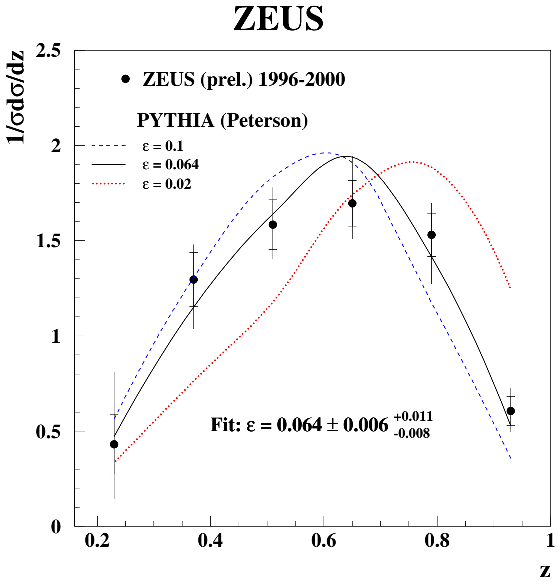
- ▷ $\eta(\mathrm{part}) > 0$ for p-remnant suppression
- ▷ thrust axis in plane perpendicular to γ used for hemisphere division



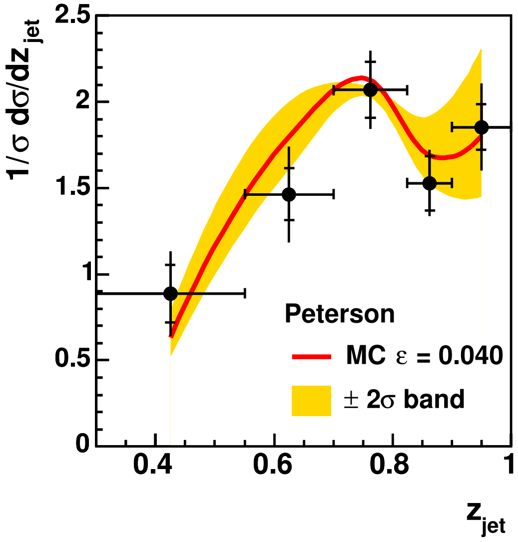
Extracted FF for Monte Carlo

▷ extracted parameters for PYTHIA, resp. RAPGAP/PYTHIA MC

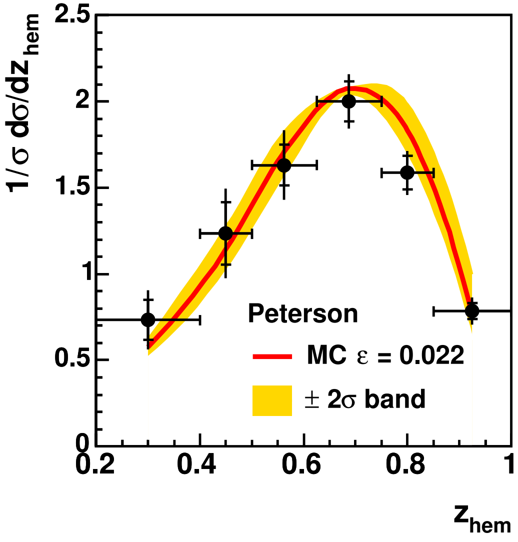
Jet method



Jet method



Hemisphere method



ZEUS Photoproduction:

$Q^2 < 1$ GeV^2

$E_t(D^*\text{jet}) > 9$ GeV

$\varepsilon = 0.064 + 0.006^{+0.011}_{-0.008}$

H1 DIS:

$2 < Q^2 < 100$ GeV^2, $0.05 < y < 0.7$

$E_t(D^*\text{jet}) > 3$ GeV, no cut on $E_t(D^*\text{hem})$

$\varepsilon = 0.040^{+0.013}_{-0.009}$, $\varepsilon = 0.022^{+0.007}_{-0.004}$

Differences. Why?

▷ **H1: differences between hemisphere and jet method**

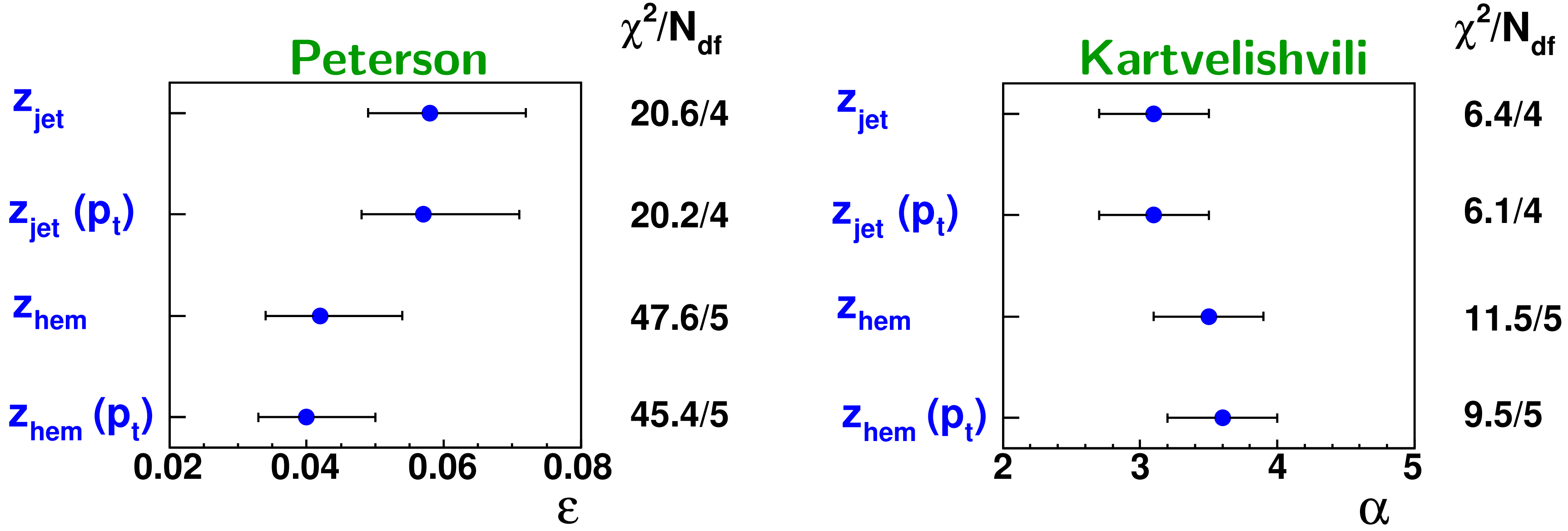
- constraining both methods to the same kinematic phase space (demand $E_{\mathrm{t}}(D^{*}\mathrm{jet}) > 3$ GeV also for hem. method) both methods give $\varepsilon \approx 0.040$ $\Longrightarrow$ **methods are consistent**
- indication for MC having problem close to kinematic threshold?
- improper parametrization FF_{np}?

▷ **difference between H1 and ZEUS jet method results**

- **different MC parameter settings:** fraction of D^{*}-mesons originating from decays of higher excited charm states $(D^{**} \rightarrow D^{*}X)$, in H1 analysis $\sim 27\%$ (ZEUS 0%)
- presence of D^{**} states results in softer FF($c \rightarrow D^{*}$) spectrum $\Longrightarrow$ the extracted fragmentation function is expected to be harder
- turning off D^{**} states in H1 $\mathrm{z}_{\mathrm{jet}}$ analysis leads to $\varepsilon = 0.075^{+0.019}_{-0.017}$, consistent with ZEUS result

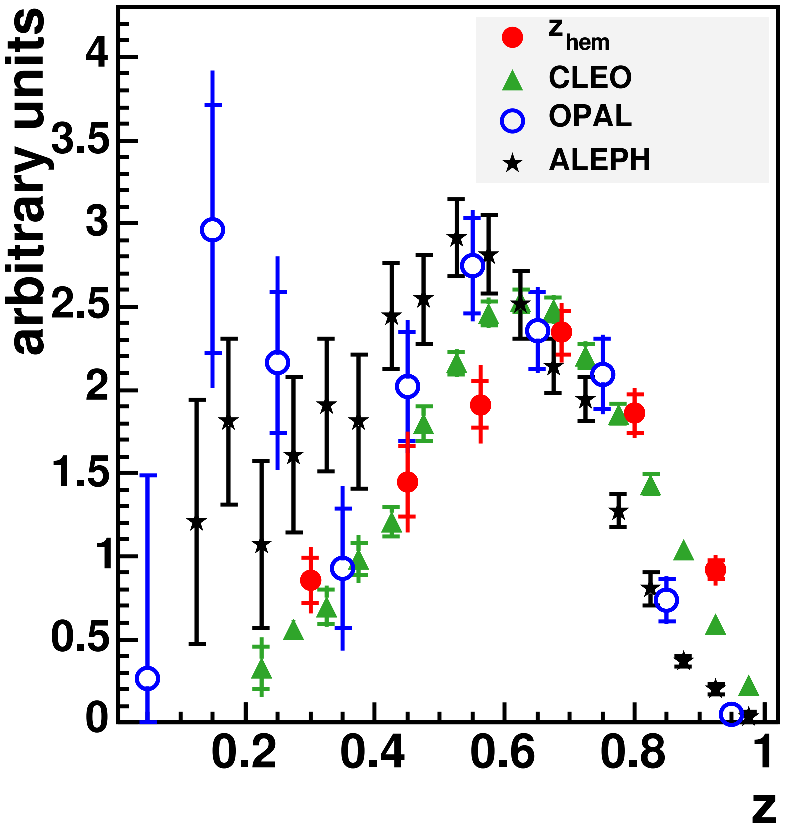
Extracted FF for NLO pQCD Calculation

- **HVQDIS:** full massive NLO pQCD calculation
- **Fragmentation procedure:** c-quarks fragment independently in γp-frame
  - D^* momentum fraction generated according to Peterson/Kartvelishvili
  - possibility to add small perp. momentum component $<p_{\rm t}(D^*)> \approx 350$ MeV
  - decay chains $D^{**} \rightarrow D^*X$ not included
- **fits performed to data distributions corrected to parton level**



Better description of data by NLOcalc + Kartvelishvili

Comparison of Experimental results I



H1 hemisphere method

$<\sqrt{\hat{s}}>\approx 8$ GeV,

$$z = \frac{(E+p_L)_{D^*}}{\sum_{hem}(E+p)}$$

CLEO $\sqrt{s} = 10.6$ GeV,

$z = p_{D^*}/p_{max}$

OPAL $\sqrt{s} = 91.2$ GeV,

$z = 2E_{D^*}/\sqrt{s}$

ALEPH $\sqrt{s} = 91.2$ GeV,

$z = 2E_{D^*}/\sqrt{s}$

▷ different observable definitions

▷ different center of mass energies, thus different pert. components as well

$\Longrightarrow$ **Direct shape comparison impossible!**

Comparison of Experimental results II

type	exp.	Parametrization		fit. value	$\chi^2_{\text{min}}/N_{\text{df}}$
e^+e^-	OPAL	Peterson	ε	$0.035 \pm 0.007 \pm 0.006$	$5.2/6$
		Kartvelishvili	α	$4.2 \pm 0.5\ \ 0.4$	$11.5/6$
		Lund	a	$1.95^{+0.78}_{-0.53} \pm 0.08$	
			b	$1.58^{+0.64}_{-0.42} \pm 0.06$	$3.4/5$
e^+e^-	ALEPH	Peterson	ε	0.034	—
e^+e^-	CLEO	Lund	a	0.18	—
			b	0.40	—
e^+e^-	BELLE	Peterson	ε	0.054	$3003/54$
		Kartvelishvili	α	5.6	$1271/54$
		Lund	a	0.58	
			b	default	$965/55$
ep	ZEUS	Peterson	ε	$0.064 \pm 0.006^{+0.011}_{-0.008}$	—
ep	H1 z_{hem}	Peterson	ε	$0.022^{+0.007}_{-0.004}$	$5.3/5$
		Kartvelishvili	α	$5.1^{+0.8}_{-0.7}$	$4.2/5$
ep	H1 z_{jet}	Peterson	ε	$0.040^{+0.013}_{-0.009}$	$3.8/4$
		Kartvelishvili	α	$3.8^{+0.6}_{-0.5}$	$4.4/4$

Direct comparison of Monte Carlo fits impossible due to different parameter settings!

How to Test FF Universality?

▷ **Idea: rerun H1 analysis with BELLE MC steering?**

- steering available, let's see if it will work

▷ **What about D^{**} states?**

- in moment we use 'ALEPH tune' ($\approx 27\%$ of D^{*} produced via D^{**} decays)
- are there any recent recommended measurements, i.e. branching fractions?