Charm Fragmentation Function

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- Introduction
- Observable definitions & measurement
- Extraction of fragmentation parameters
- Universality issues

Introduction

- QCD – predictions usually based on perturbative calculations
  ==> at long distances not applicable
- **Factorization theorem:** allows to separate process into short distance part (perturbative) associated with large momentum transfer and long distance part (non-perturbative, but universal)
- **Production cross-section for inclusive process ep->H+X:**

$$\sigma_H = \sum_i \sum_k f_{i/p}(x, \mu_\mathrm{f}) \otimes \hat{\sigma}_{i\gamma\rightarrow kX}(\alpha_\mathrm{s}(\mu_\mathrm{r}), \mu_\mathrm{r}, \mu_\mathrm{f}) \otimes D_k^H(z, \mu_\mathrm{f})$$

Parton Density Function ***Hard Scattering (perturbative)*** ***Fragmentation Function***

Fragmentation Function

- **Fragmentation Function (FF):** provides information about the energy fraction **z** transferred from parent quark to the created hadron

$$z=(E+P_L)_{D*}/(E+P)_c$$

- **Phenomenological models:** Lund string (PYTHIA MC), cluster (HERWIG MC)

- **Phenomenological parametrizations:** Peterson, Kartvelishvili, Bowler with a tunable parameters

- **charm FF already precisely measured in e+e-**
  ==> with ep data we can check if universality holds
  (i.e. if they are portable from e+e- to ep and pp collisions)

Choice of Fragmentation Observable

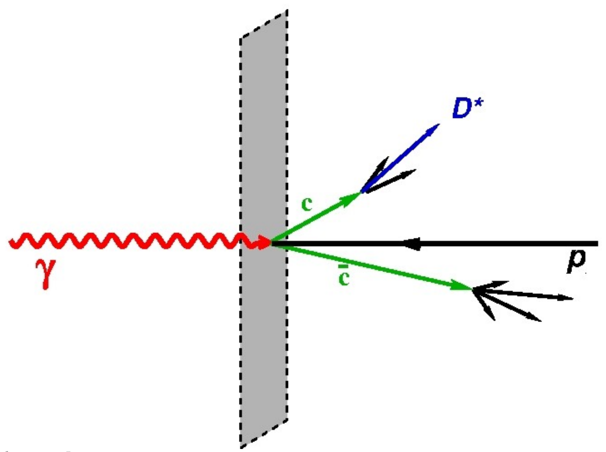
- **Fragmentation functions cannot be measured directly, since only hadrons are observed !**

Jet method:

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

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

- ▷ $k_\perp$-clus jet algorithm applied in γp-frame ($E_{\text{t}}(D^* jet) > 3$ GeV)

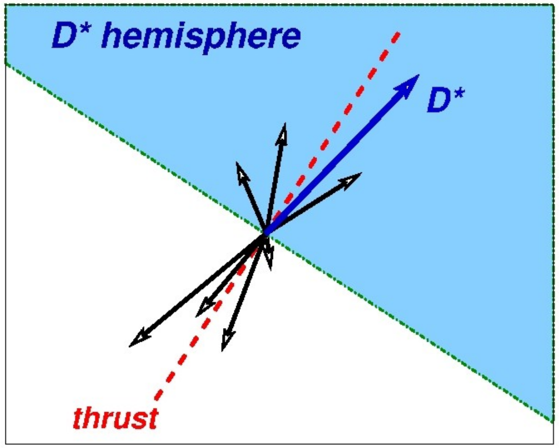


Hemisphere method:

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

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

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



D* Selection

Cuts:

- **DIS cuts:**
  - $2 < Q^2 < 100\ GeV^2$
  - $0.05 < y_e < 0.7$
  - **$40 < E\text{-}p_z < 75$ GeV**
  - **$|z_{vtx}| < 35$ cm**
- **D* cuts:**
  - $|\eta(D^*)| < 1.5$
  - $1.5 < p_t(D^*) < 15$ GeV
  - **$p_t(K,\pi) > 0.25$ GeV**
  - **$p_t(\pi_s) > 0.12$ GeV**
  - **$p_t(K) + p_t(\pi) > 2$ GeV**
  - **$|M(K,\pi) - M(D^0)| < 70$ MeV**
  - **particle identification via dE/dx**

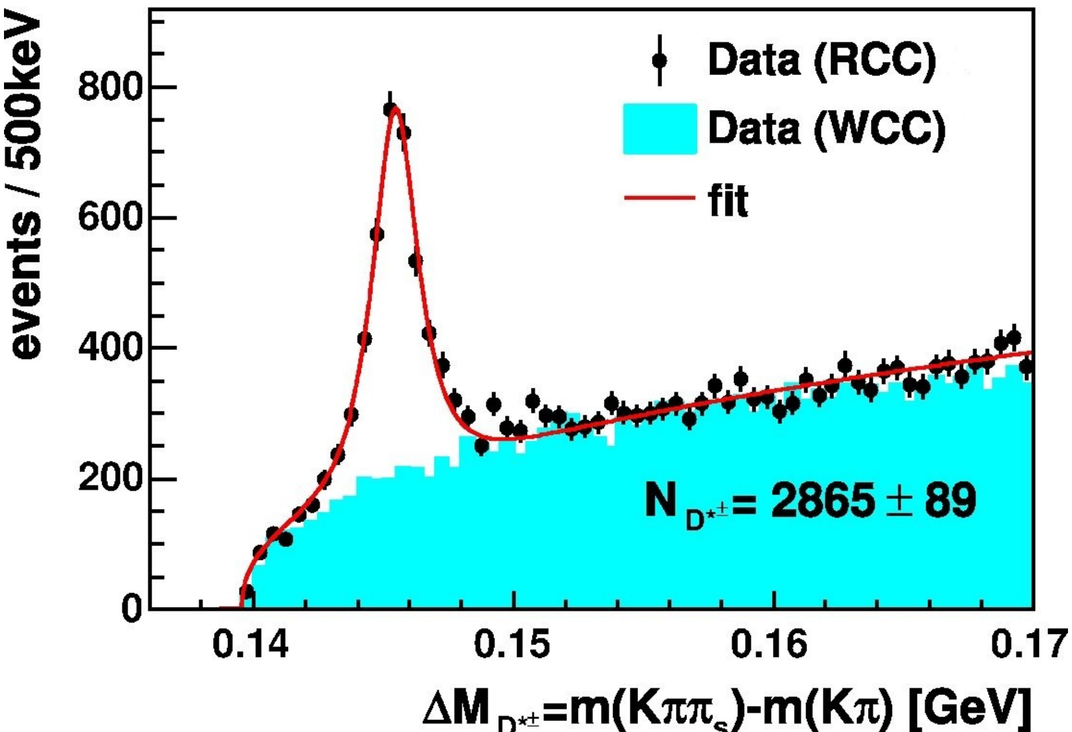
Golden channel: $D^* \to D^0\pi_s \to K\pi\pi_s$

1999+2000 data: Luminosity≈47 pb^{-1}

full sample N(D*)≈2900,

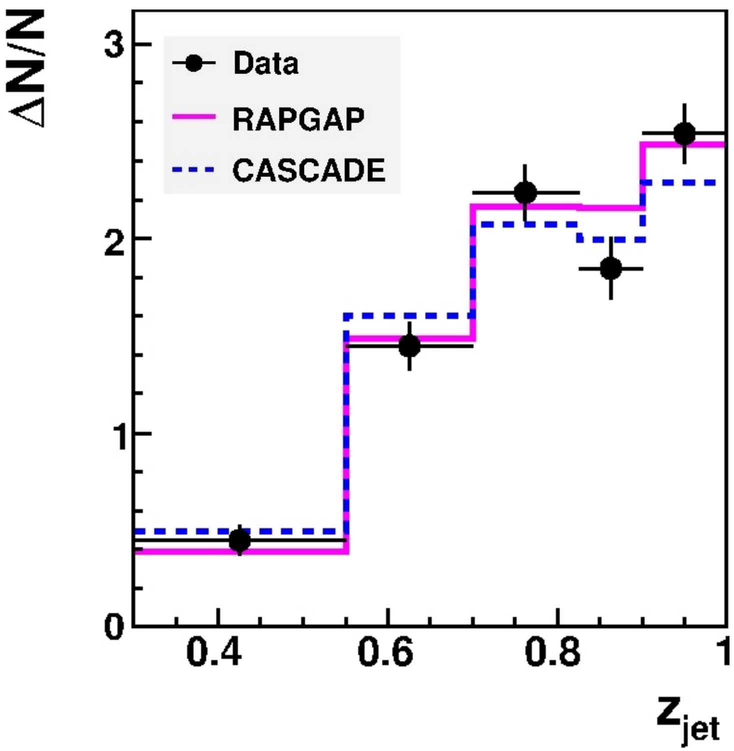
for E_t(D*jet)>3GeV N(D*)≈1500

Fit: Mod. Gauss + bg. function

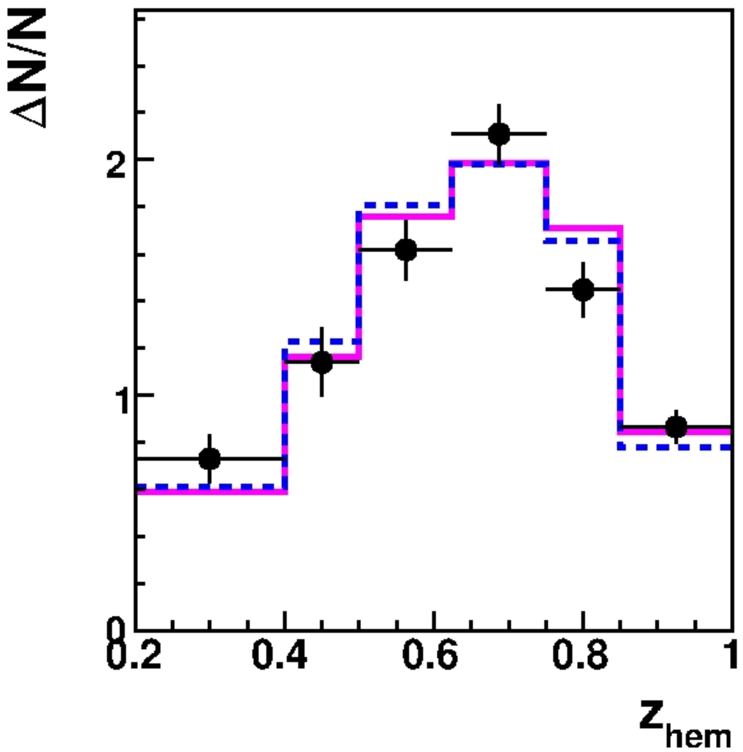


Observables at Detector Level

Jet method



Hemisphere method



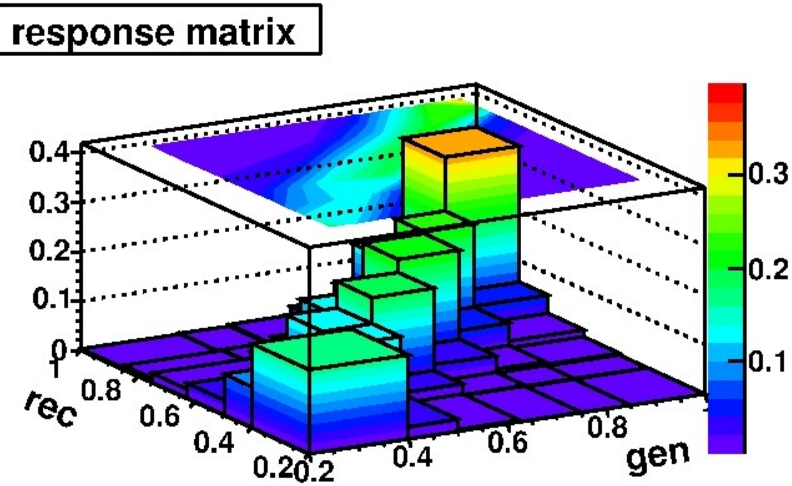
- differences between observables in the last z bin due to significant fraction of D*jets consisting of a D*meson only

Correction Procedure

- **Subtraction of beauty component**
  - done at detector level, using bb RAPGAP MC prediction (fraction bellow 2%)
- **Correcting for detector effects**
  - regularized unfolding procedure applied, migrations from one bin into another taken into account by detector response matrix (essential for correct statistical error propagation in case of low purities)
- **QED radiative corrections**
  - calculated by RAPGAP/HERACLES

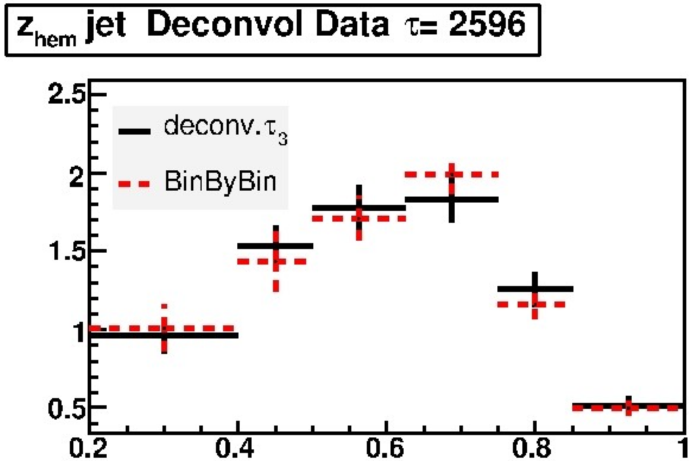
SVD Unfolding z_hem

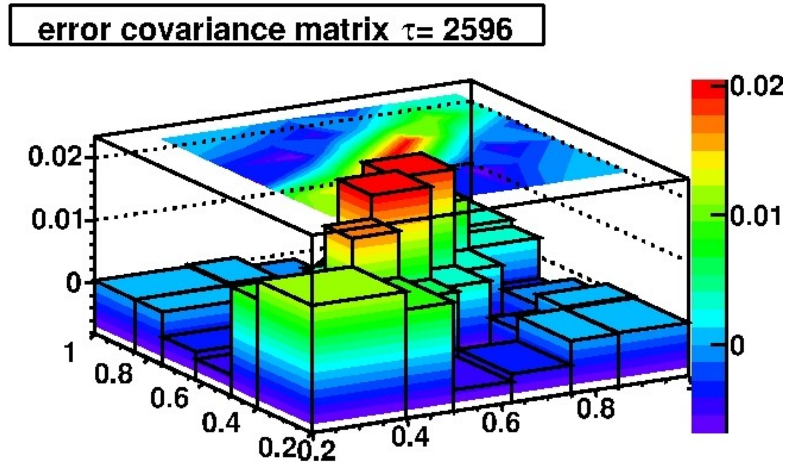
Detector response matrix



Unfolded z_{hem} distribution,

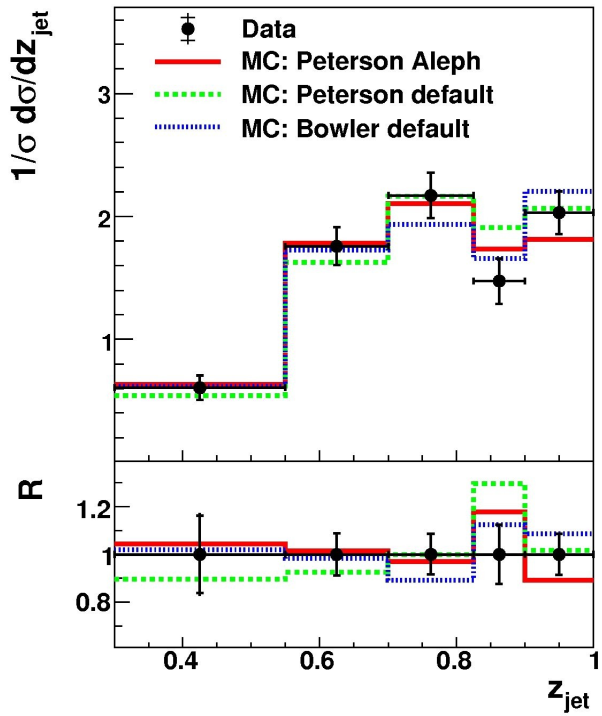
D*jet sample (statistical errors only):



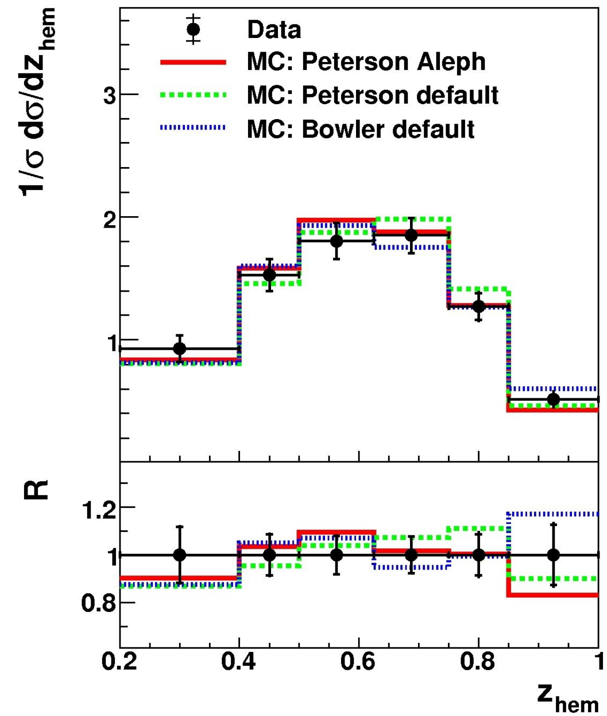


Hadron Level Corrected Frag. Obs.

Jet method



Hemisphere method



- observables compared with different MC fragmentation tunes
  - **Default** = Rapgap out of the box, no higher resonances present (c->D*)
  - **Aleph tune**, contains ~ 27% of higher resonances (c->D* and c->D**->D*)
- good description of both observables

Averaged Systematic Errors (summary)

	Zhem [%]	Zjet [%]
Ee	0.8	0.5
Theta_ e	0.1	0.1
dE/dx	0.1	0.3
D*signal extr.	1.7	1.7
Energy scale	3	2.5
Trk. Scale	0.2	0.2
Trk eff.	0.1	0.1
Beauty	1.2	0.9
Model	0.1	0.3
Tot. sys. err.	3.8	3.4
Stat err.	10	10.9

<-- Statistical error dominant!

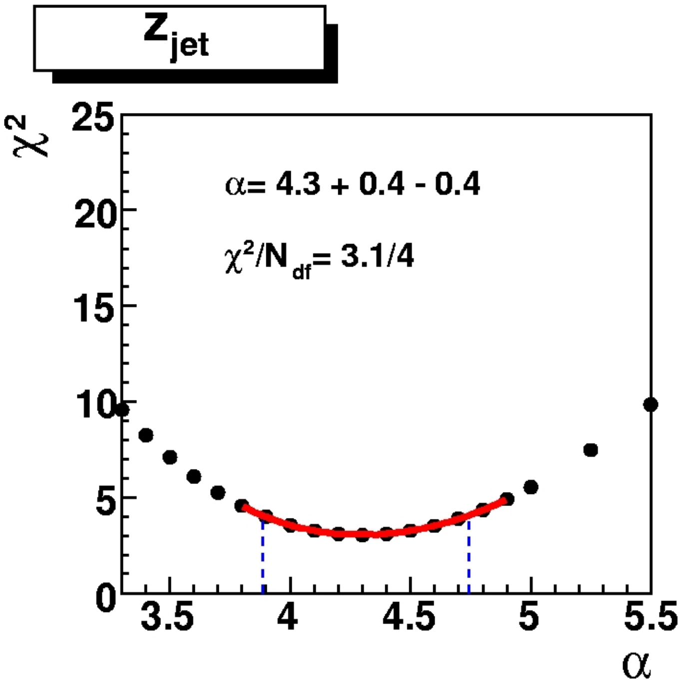
- Sys. errors due to uncertainty of energy scale, electron energy and beauty fraction are **correlated** in z bins

FF Extraction Procedure

Non-pert. Frag. function defined only within given theoretical model:

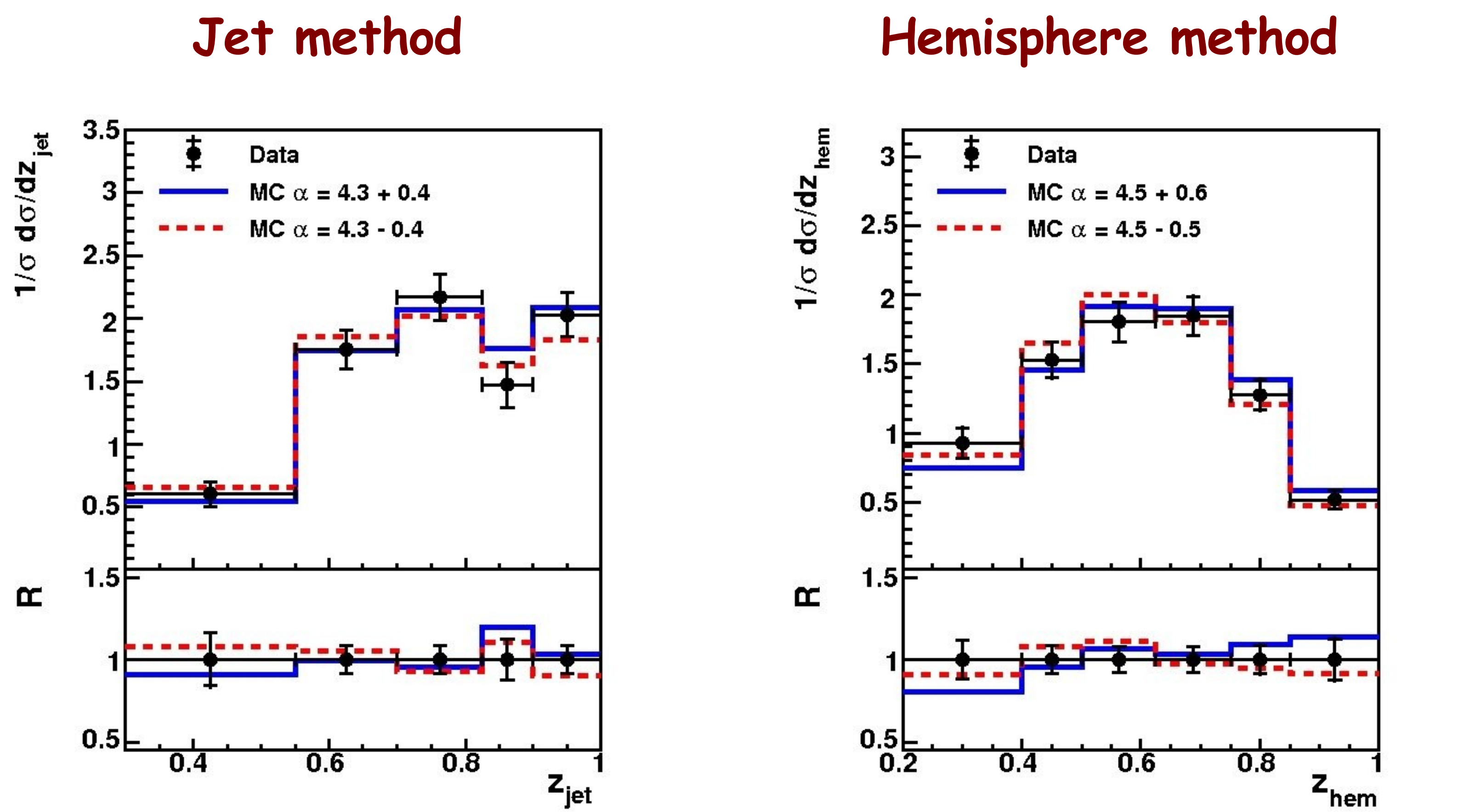
- **LO+PS Monte Carlo models** RAPGAP and CASCADE with Lund string fragmentation model (default setting, Aleph setting)
- **NLO calculations** (HVQDIS)
- **Fitted parametrizations of non-pert. FF:** Kartvelishvili, Peterson
- **optimal parameters and confidence limits obtained from chi2** (correlated statistical and sys. errors taken into account)

$$\chi^2(\varepsilon) = (\mathrm{z} - \mathrm{z}^{\mathrm{MC}}(\varepsilon))^{\mathrm{T}} \mathrm{V}^{-1} (\mathrm{z} - \mathrm{z}^{\mathrm{MC}}(\varepsilon))$$



Extracted FF Plots - MC

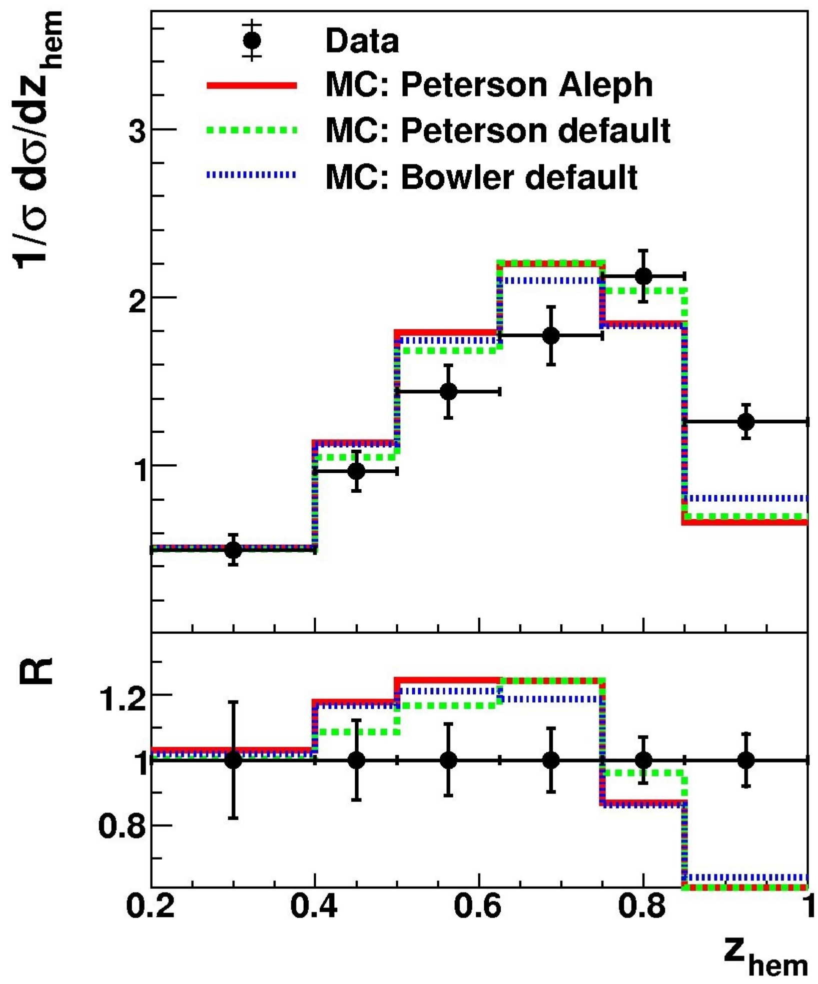
Rapgap with Aleph setting & Kartvelishvili parametrization:



- both methods agree well within errors!

Investigating the Threshold Region

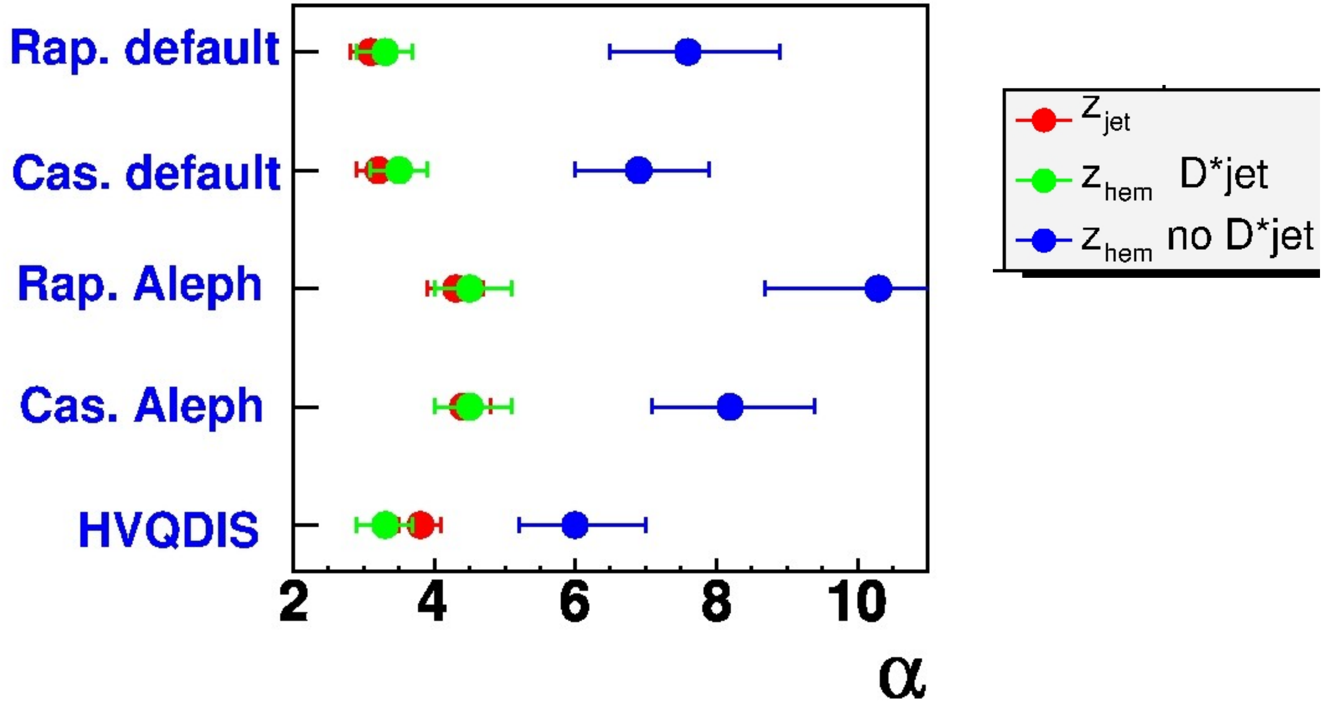
- events not fulfilling hard scale cut Et(D*jet)>3GeV, roughly 1300 D* events
  ==> inclusion would improve the statistical errors
- data spectrum much harder, data events have different topology than MC
- extracted FF roughly 4σ far from the FF extracted from the nominal sample
- discrepancy due to improper description of underlaying physics close to the charm production threshold in MC models



α Fit Results (Summary)

Rapgap MC

Aleph tune, Kartvelishvili parametrization:



- **Qualitatively similar picture obtained also with Peterson parametrization**

Universality Issues (Comparison with e+e-)

- **Direct comparison of measured data impossible because:**
  - 1.) different observable definitions used : $z_{e+e-}=E_{D*}/E_{beam}$, $z_{e+e-}=P_{D*}/P_{max}$, $z_{jet}=(E+P_L)_{D*}/(E+P)_{jet}$, $z_{hem}=(E+P_L)_{D*}/(E+P)_{hem}$
  - 2.) measurements performed in different phase space:

ALEPH, OPAL	$\sqrt{s}=91.2GeV$
CLEO, BELLE	$\sqrt{s}=10.6GeV$
H1	$\sqrt{\langle \hat{s} \rangle}=10GeV$

- **Comparison of extracted FF parameters relevant, but one needs to keep a track of what**
  - 1.) perturbative calculation have been used
  - 2.) which MC fragmentation parameter tune have been used

Peterson Fits with Aleph PYTHIA Tune

(work done by our sumer student Thomas Lubbert)

- PYTHIA/RAPGAP MC with most recent ALEPH parameter tune used
- Peterson FF parameter fits performed with BELLE, ALEPH and this ep data

	ALEPH	BELLE	zjet	zhem
epsilon	0.042 +/- 0.013	0.032 +/-0.004	0.035 +/-0.007	0.029 +/-0.007

Within errors rather consistent picture obtained!