Study of Charm Fragmentation Function at H1

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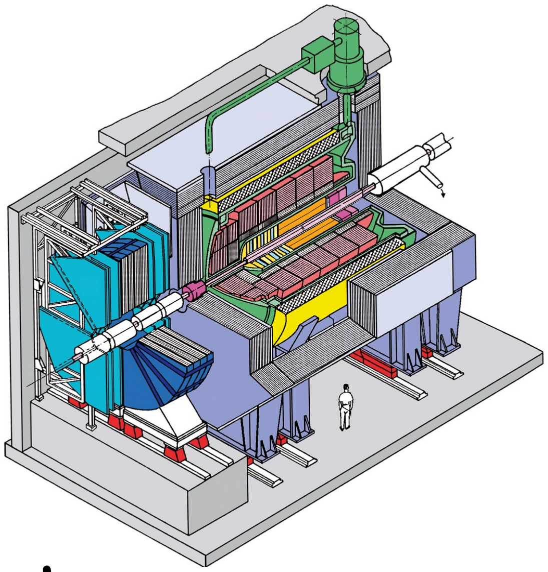
for H1 Collaboration

Fragmentation workshop, Trento
25.-29. February 2008



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

Introduction

- Production cross-section for inclusive process ep->H+X:

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

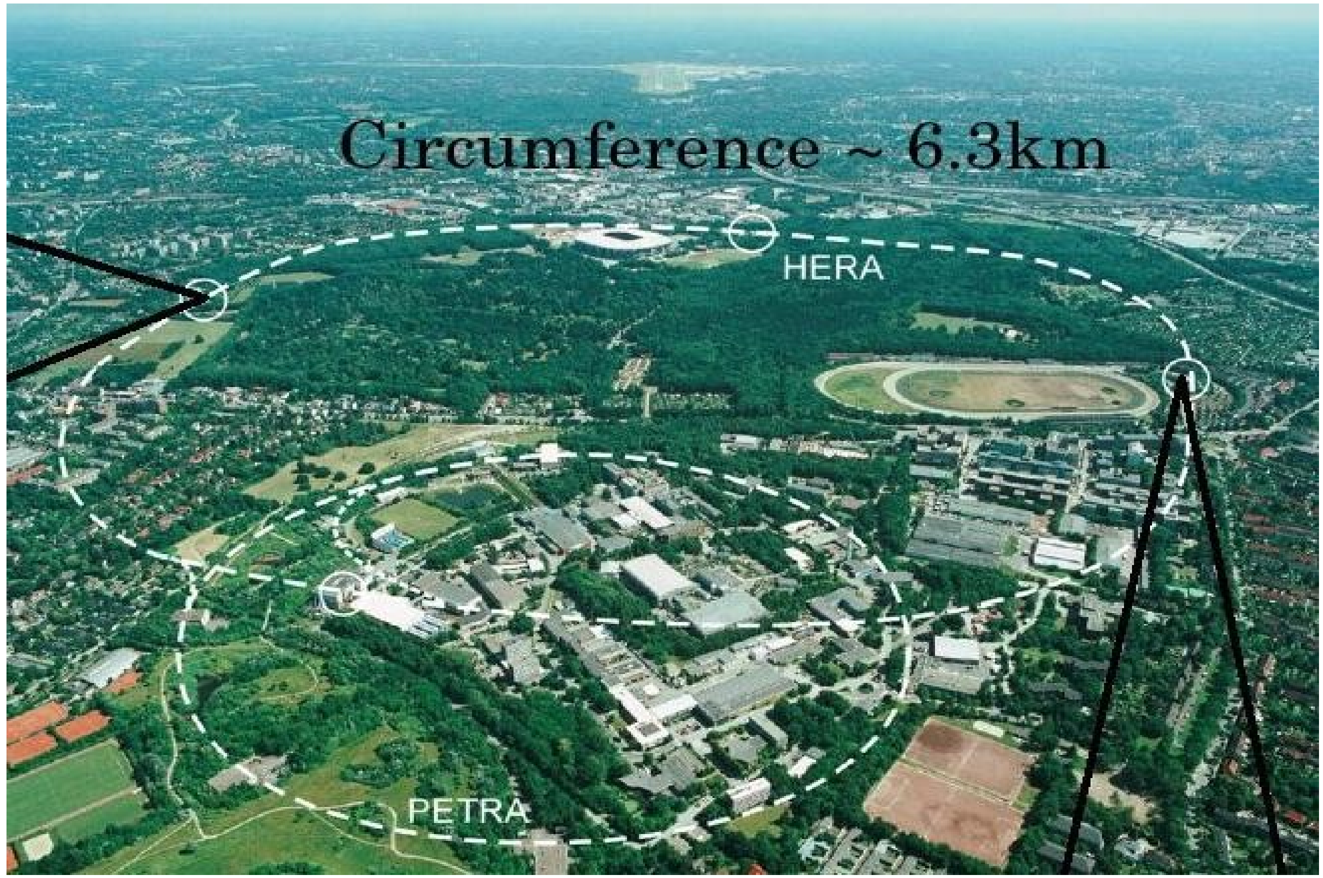
Parton Density Function

Hard Scattering (perturbative)

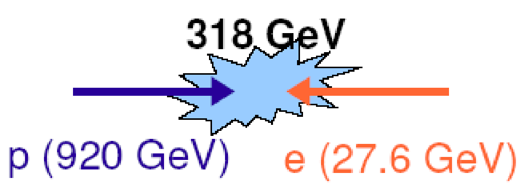
Fragmentation Function

- Fragmentation functions FF:
  - non-perturbative process ==> need to be experimentally studied
  - charm FF already precisely measured in e^+e^-
  - with ep data we can check if universality holds

H1 & HERA Collider



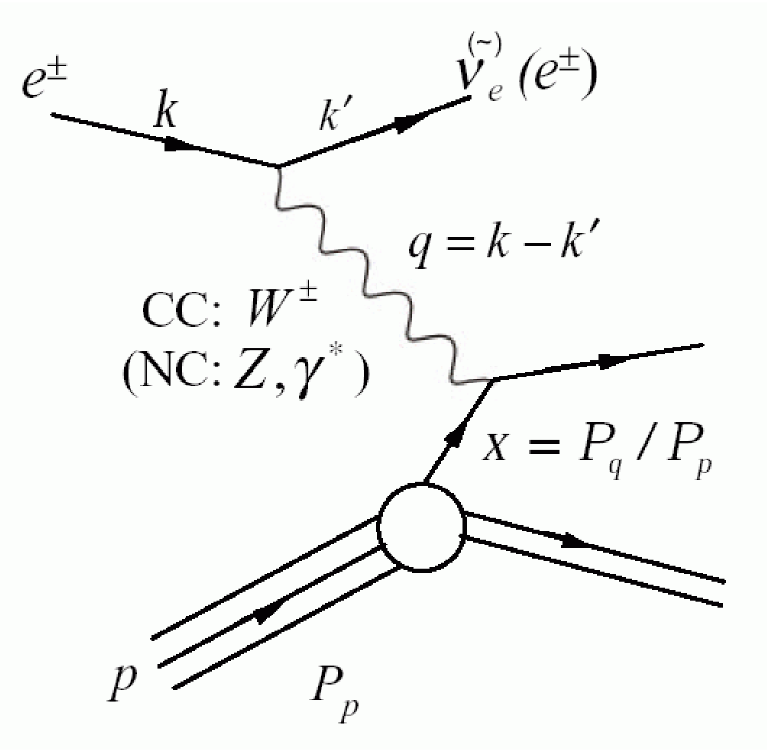
HERA:



1999+2000 HERA I data:

Luminosity≈47 pb^{-1}

ep Event Kinematics



- **Four-momentum transfer:**

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

- **Inelasticity:**

  $y = Pq/Pk$

- **Boson-proton center of mass energy:**

  $W = (q+P)^2 \approx ys - Q^2$

QCD Models

	Rapgap 3.1	Cascade 1.2	HVQDIS
Type	LO+PS	LO+PS	FO NLO(massive)
Evolution	DGLAP	CCFM	DGLAP
Proton PDF	CTEQ5L	A0	CTEQ5F3
Photon PDF	SaS-G2D		
Scale	Q2+pt2	4mc2+pt2	4mc2+Q2
Mc	1.5	1.5	1.5
Fragmentation	Lund string	Lund string	Independent

As implemented in Pythia 6.2

- Default setting: Pythia from the box (no D**->D*X)
- Aleph setting: includes higher resonances (~27% D* originating from D**->D*X)

"hand made" fragmentation

- c-quarks fragmented in γp frame
  $p_L(D^*)$ generated according to given parametrization (D* put on mass shell)

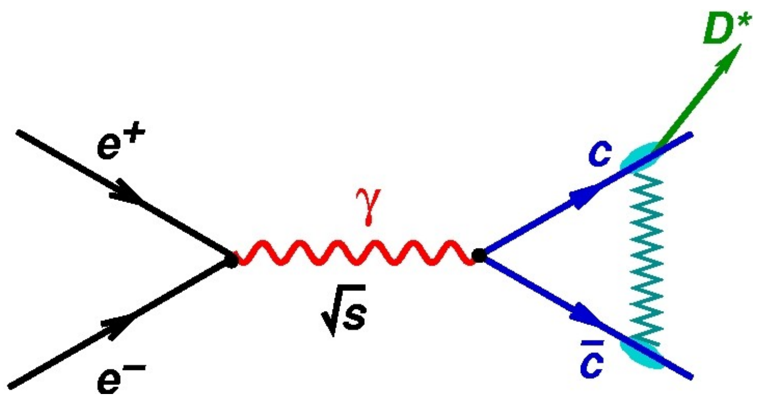
Choice of Fragmentation Observable

e+e- collisions

- natural choice:

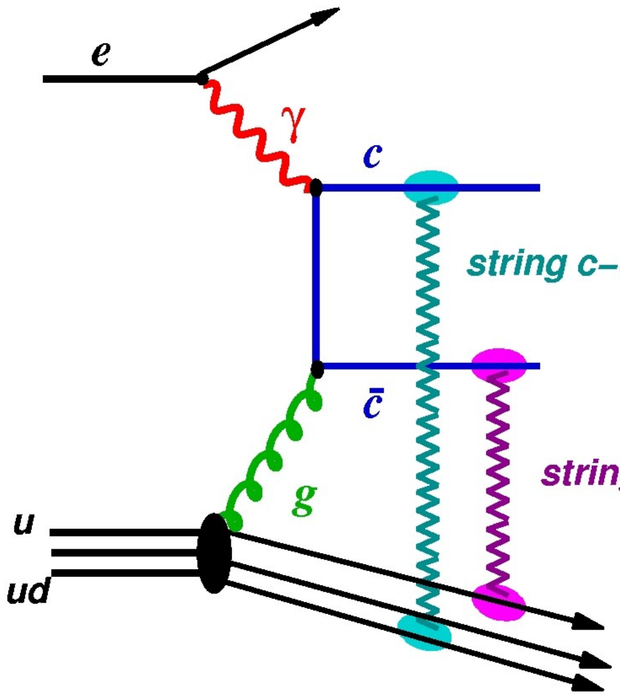
  $z = E_{D^*}/(\frac{1}{2}\sqrt{s}) = E_{D^*}/E_{BEAM}$

- in LO approximation $E_{BEAM} = E_c$
  ==> z corresponds to direct measurement of FF



ep collisions

- √s of hard subprocess unknown
  ==> choice of observable not obvious
- differences: presence of IPS
  different color flow



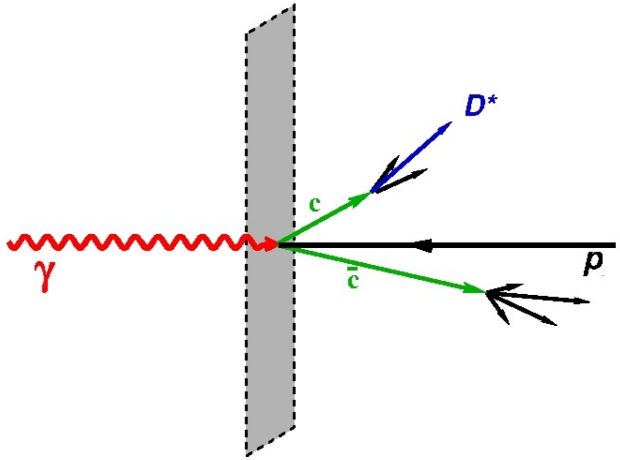
Definitions of Observables

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)



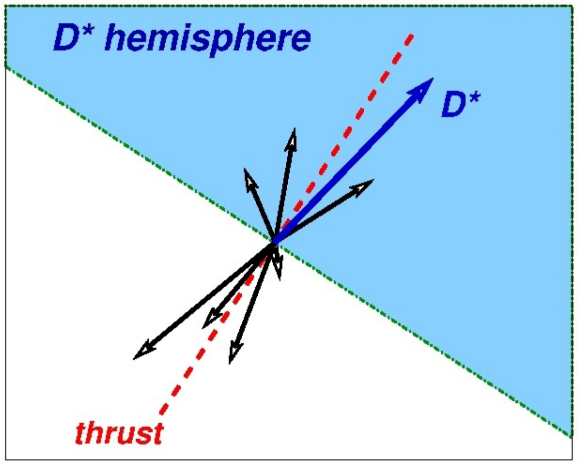
Hemisphere method:

▷ 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

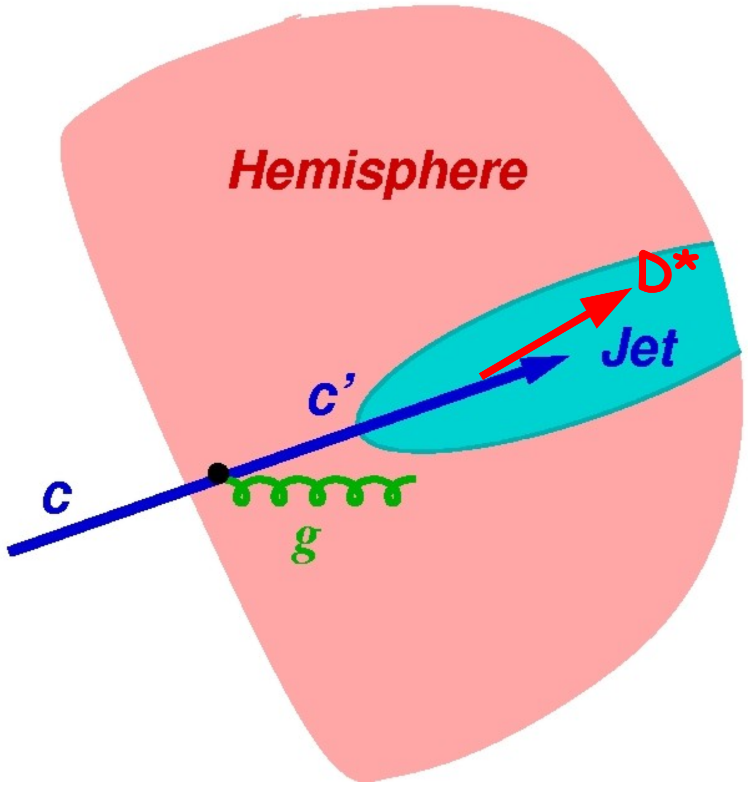
▷ thrust axis in plane perpendicular to γ used for hemisphere division



Comparison of Observables

Hemisphere Method:

- Sums more gluon radiation than jet method



Interesting to measure both $d\sigma/z_{hem}$ and $d\sigma/z_{jet}$ because:

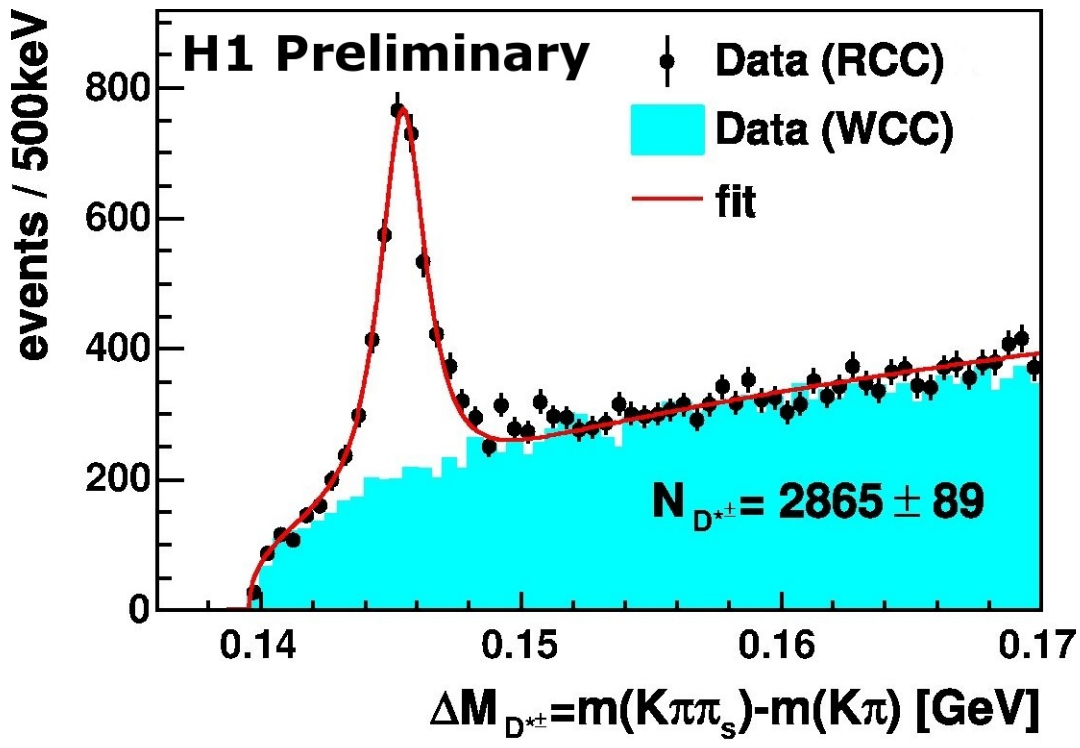
- Allows to test understanding of parton radiation
- Both distributions should look differently, but extracted non-pert. FF should be the same if model is perfect

D* Selection

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

- **DIS cuts:**
  - $2 < Q^2 < 100$ GeV^2
  - $0.05 < y_e < 0.7$
- **D* cuts:**
  - $|\eta(D^*)| < 1.5$
  - $1.5 < P_T(D^*) < 15$ GeV
  - $E_T(D^*jet) > 3$GeV
- after E_T jet cut

  $N(D^*) \approx 1500$

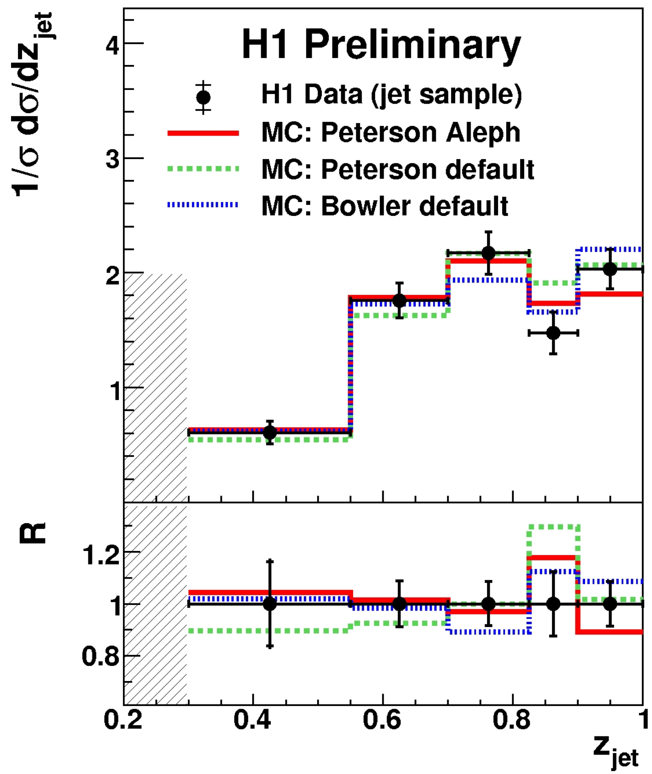


Correction Procedure

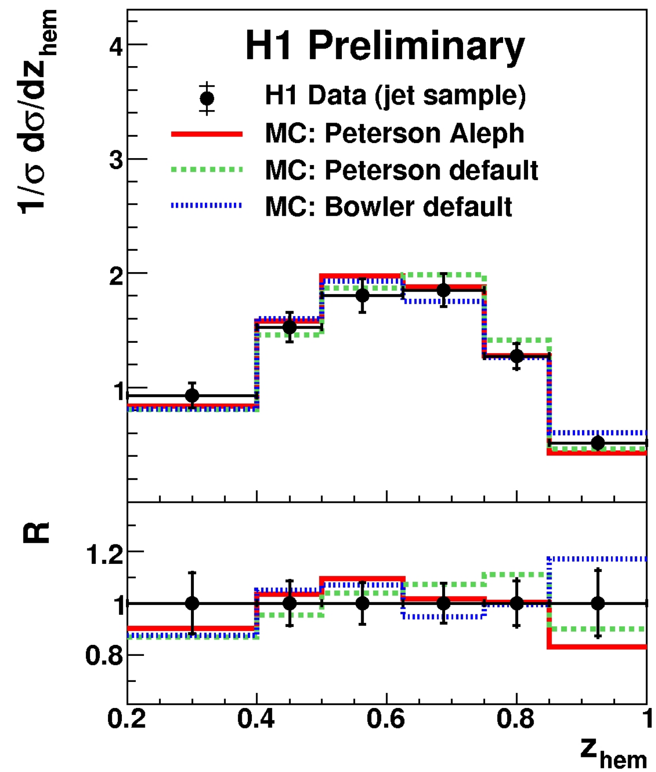
- **Subtraction of beauty component**
  - using bb RAPGAP MC prediction (fraction below 2%)
- **Correcting for detector effects**
  - regularized unfolding procedure applied, migrations from one bin into another one taken into account by detector response matrix
- **QED radiative corrections**
  - calculated by RAPGAP/HERACLES

Frag. Observable Distributions

Jet method

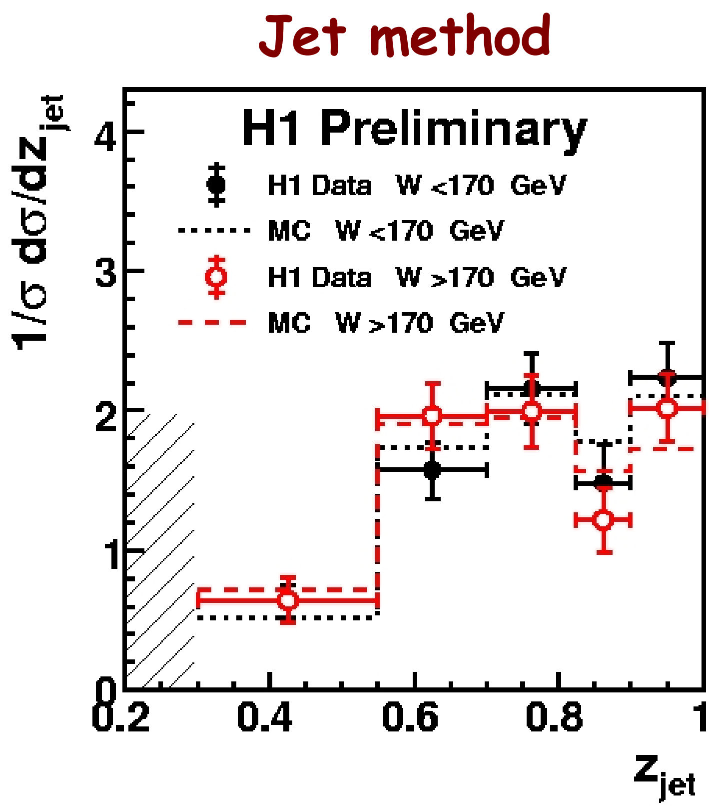


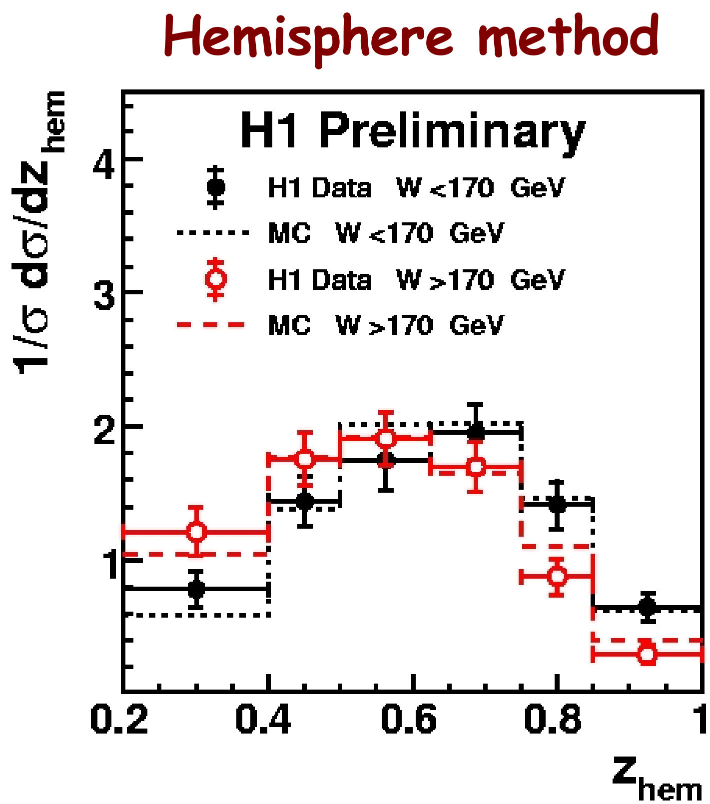
Hemisphere method



- observables compared with different MC fragmentation tunes (Rapgap/Pythia):
  - **Default:** Pythia out of the box, no higher resonances present (c->D*), ε=0.05
  - **Aleph tune:** contains ~27% of higher resonances (c->D*, c->D**->D*), ε=0.04
- *Good agreement found*

Observables as Function of W





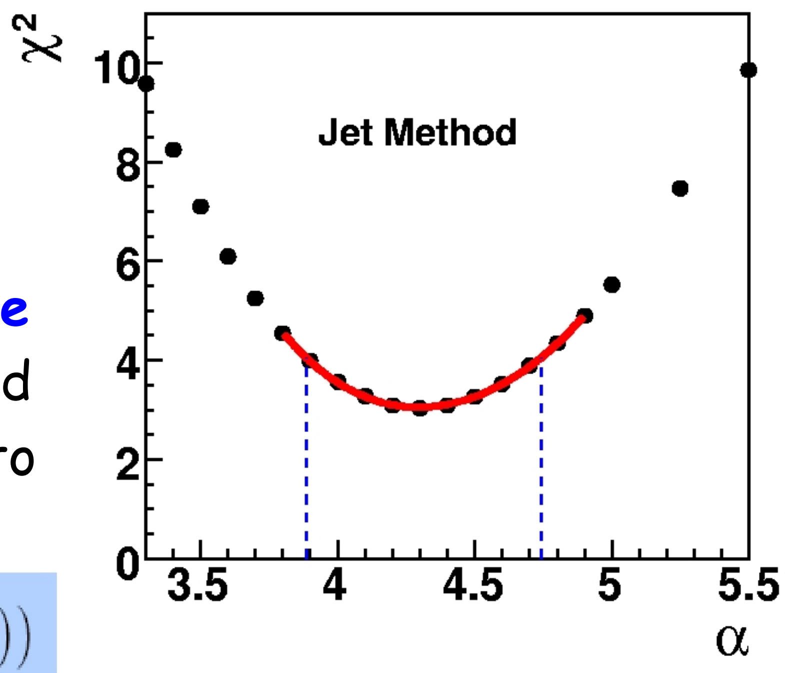
- z as function of γp cms energy –W
  - MC follows the trend in data
  - z_{hem} includes more gluon radiation than z_{jet} --> scale dependence more pronounced

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 as implemented in PYTHIA (default setting, Aleph setting)
- **NLO calculations** (HVQDIS)
- **Fitted parametrizations of non-pert. FF:** Kartvelishvili, Peterson
- **optimal parameters and confidence limits obtained from χ^2** (correlated statistical and sys. errors taken into account)

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

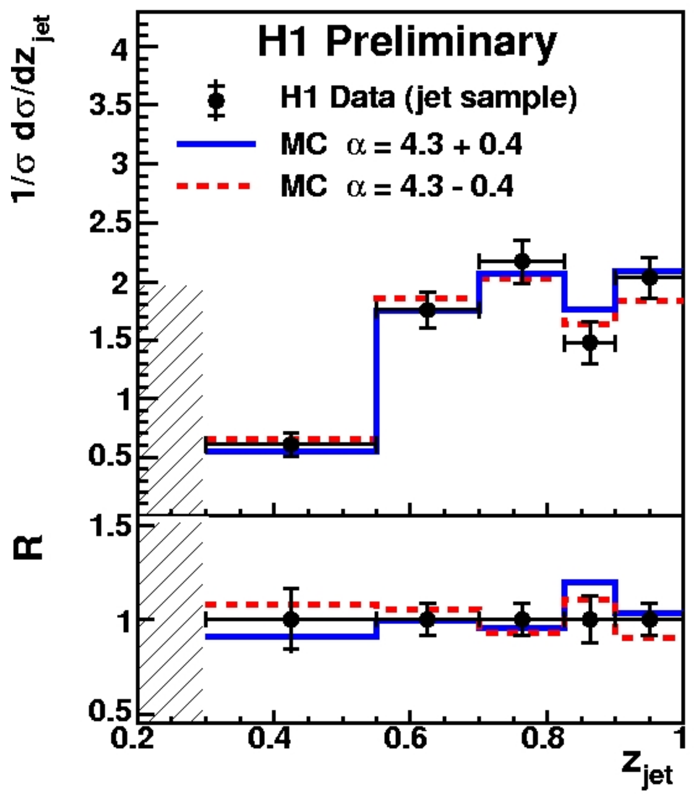


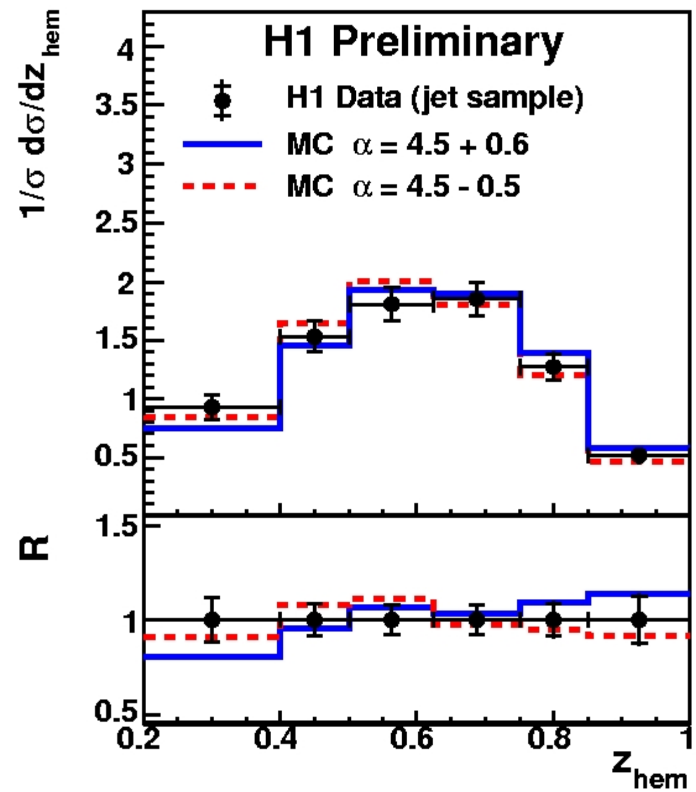
Extracted FF Plots - MC

Rapgap with Aleph setting & Kartvelishvili parametrization:

(best fit +/- 1σ error shown)

Jet method **Hemisphere method**





- both methods agree well with each other within errors

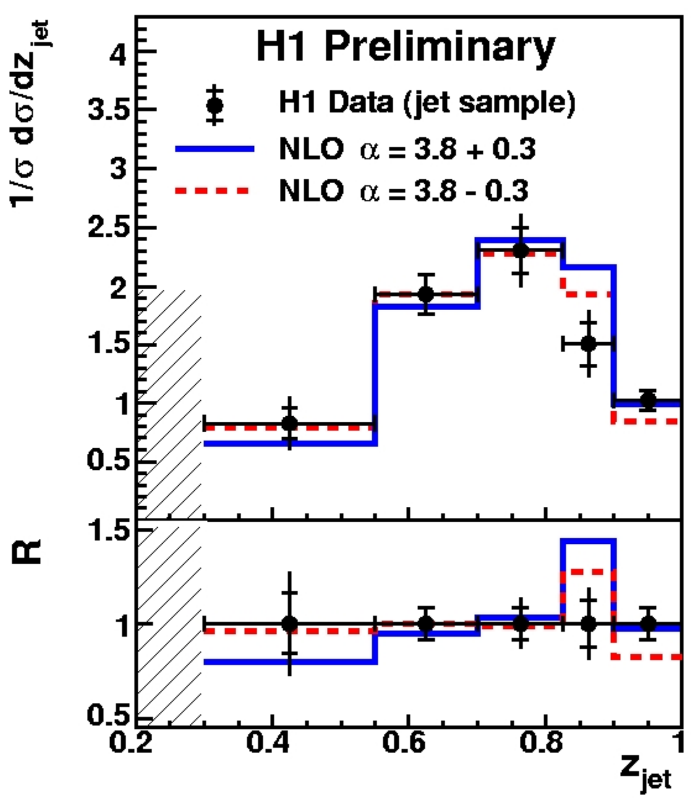
Extracted FF Plots - NLO

HVQDIS: massive NLO calculation

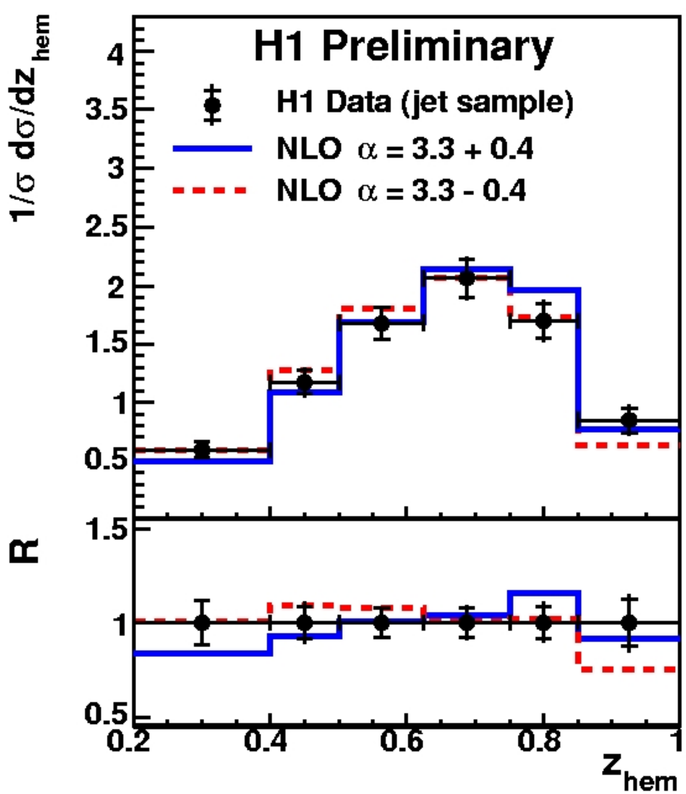
(m_c=1.5 GeV, $\mu_r=\mu_f=\sqrt{(Q2+4m_c2)}$, proton PDF= CTEQ5F3)

- **data corrected to parton level** & compared with NLO partonic cross-sections (c-quark fragmented independently in γ*p-rest frame)

Jet method



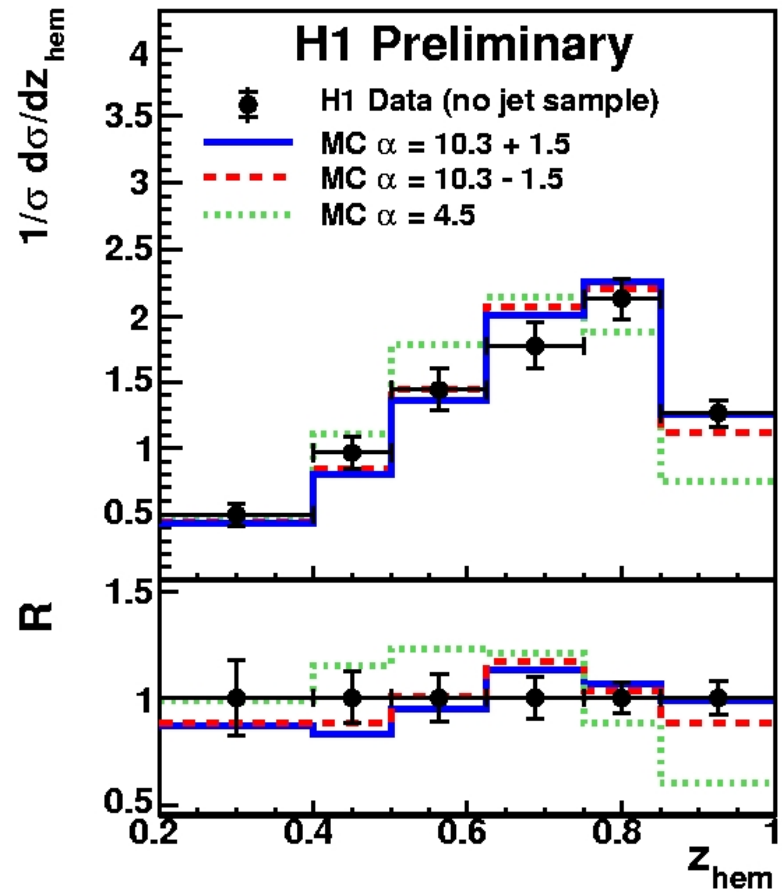
Hemisphere method



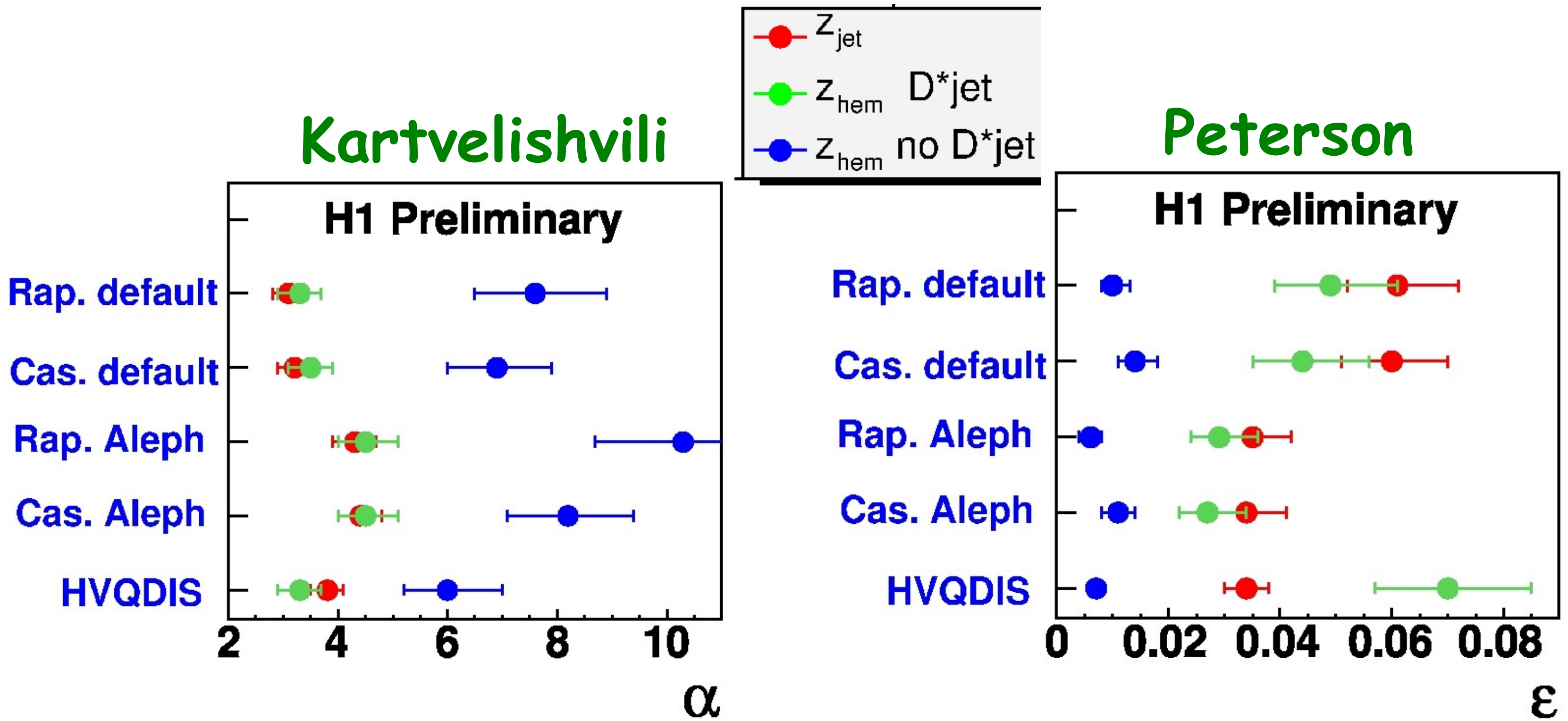
Investigating the Threshold Region

- events not fulfilling hard scale cut E_T(D*jet)>3GeV (roughly 1300 D* events) ==> hemisphere method has to be used
- extracted FF almost 4σ far from the FF extracted from the nominal sample (**spectrum much harder!**)
- discrepancy due to improper description of underlying physics close to the charm production threshold in QCD models
- NLO (HVQDIS) completely fails to describe the data (χ^2_{MIN}/N_{df} ≈40/4)

Rapgap with Aleph tune and Kartvelishvili FF:



FF Parameter Fit Results (Summary)



- extracted Peterson parameter values in agreement with the ε parameter in the Aleph tuned steering (ε=0.04)
  --> Confirms charm fragmentation universality between e^+e^- and ep, if hard scale is involved !

- Peterson and Kartvelishvili parametrizations describe the data well, only in case of NLO Peterson strongly disfavored ($\chi^2_{MIN}/N_{df} \approx 8$)

Conclusions I

- charm fragmentation studied with ep data at H1 experiment:
  - two different observable definitions z_{jet} & z_{hem} used
  - reasonable description of data by QCD models found
- FF parameters extracted for LO+PS MC models and NLO, using Peterson and Kartvelishvili parametrizations:
  - both FF observables lead to consistent parameter values
  - ep FF parameters consistent with e^+e^- FF parameters --> FF universality!
- Investigating threshold region with z_{hem}:
  - poor description of data by MC
  - NLO (HVQDIS) fails completely
- We don't understand charm physics over the full phase space

Conclusions II

- Understanding of charm fragmentation is crucial for high precision measurements at HERA

More theory input needed!