Study of Charm Fragmentation at H1

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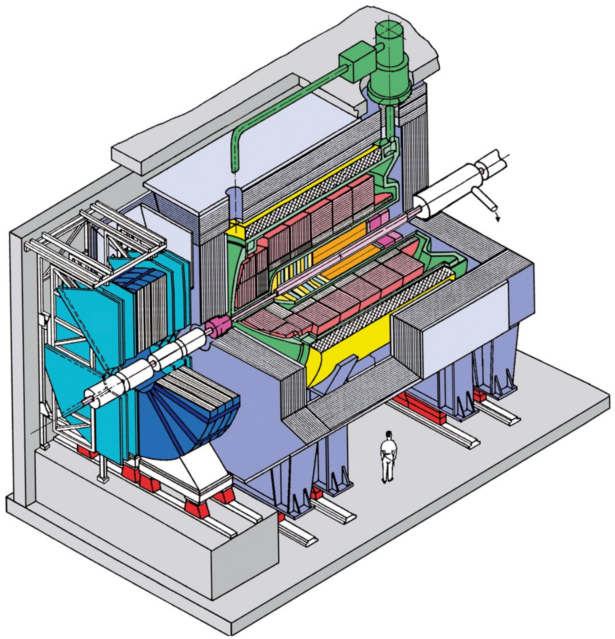


- Introduction
- Observable definitions & measurement
- Extraction of fragmentation parameters

Introduction

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

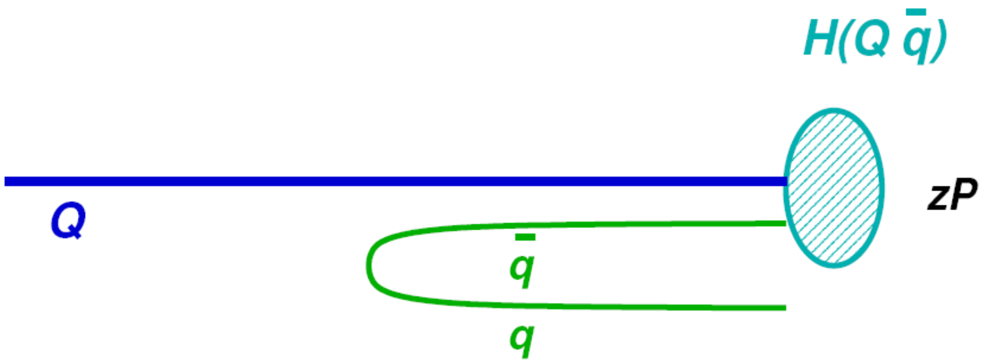
$$\sigma_H = \sum_i \sum_k f_{i/p}(x, \mu_{\rm f}) \otimes \hat{\sigma}_{i\gamma\to kX}(\alpha_{\rm s}(\mu_{\rm r}), \mu_{\rm r}, \mu_{\rm f}) \otimes D_k^H(z, \mu_{\rm f})$$

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

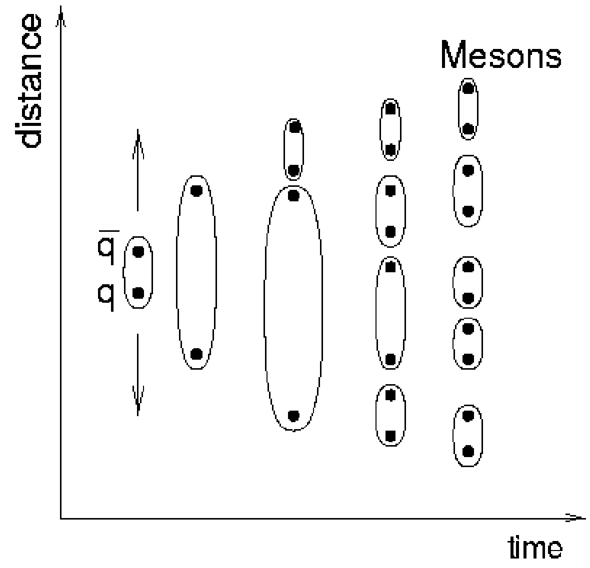
- Functions $D_k^H(z, \mu_f)$:
  - Contain non-perturbative part (FF) ==> needs to be experimentally studied
  - charm FF have been studied in e^+e^-

Fragmentation - theoretical description 1.

Independent fragmentation



Lund string model



All models use phenomenologic parametrizations of FF tuned to e+e- data!

Fragmentation - theoretical description 2.

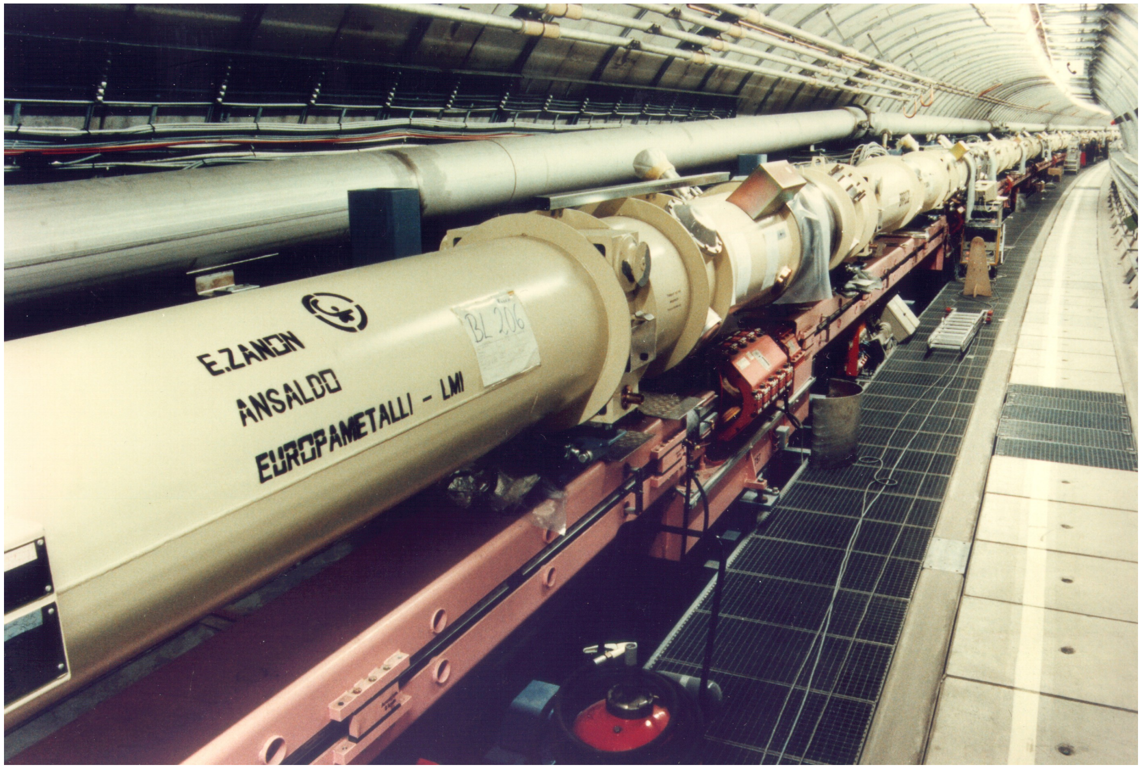
Peterson et al.: $$D_{\mathrm{Q}}^{\mathrm{H}}(z) \propto \frac{1}{z[1-(1/z)-\varepsilon/(1-z)]^2}$$

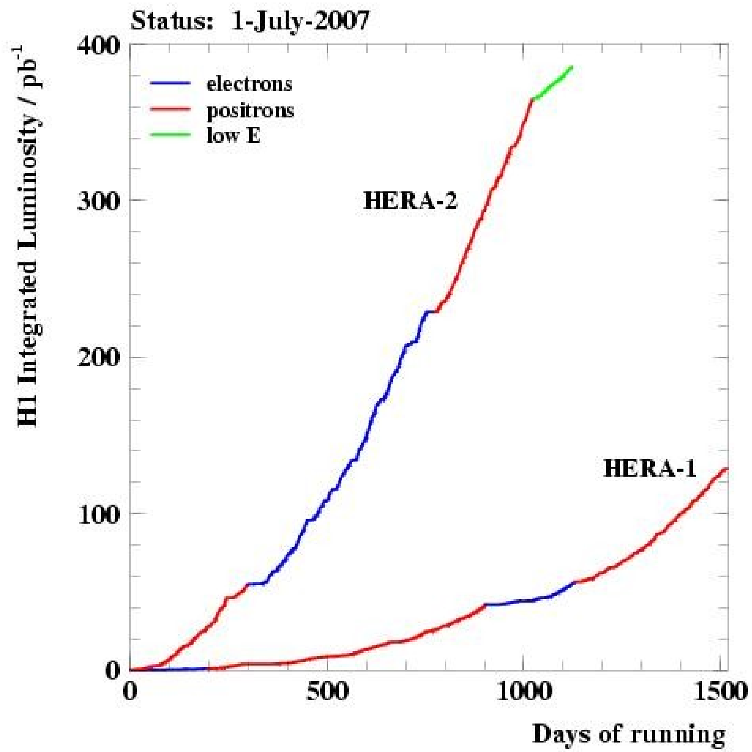
Kartvelishvili et al.: $$D_{\mathrm{Q}}^{\mathrm{H}}(z) \propto z^{\alpha}(1-z)$$

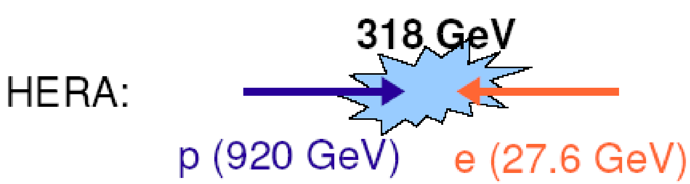
$\Rightarrow$ interesting to check, how well this approach works in ep

Understanding the charm fragmentation is crucial for high precision measurements in charm sector at HERA!

ep physics at HERA collider







HERA I+II data:

Luminosity≈0.5 fb^{-1}

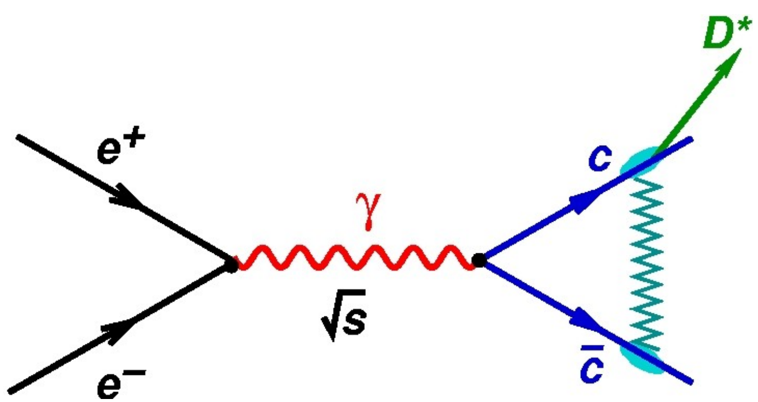
Fragmentation in e^+e^- and ep

e+e- collisions

- natural choice:

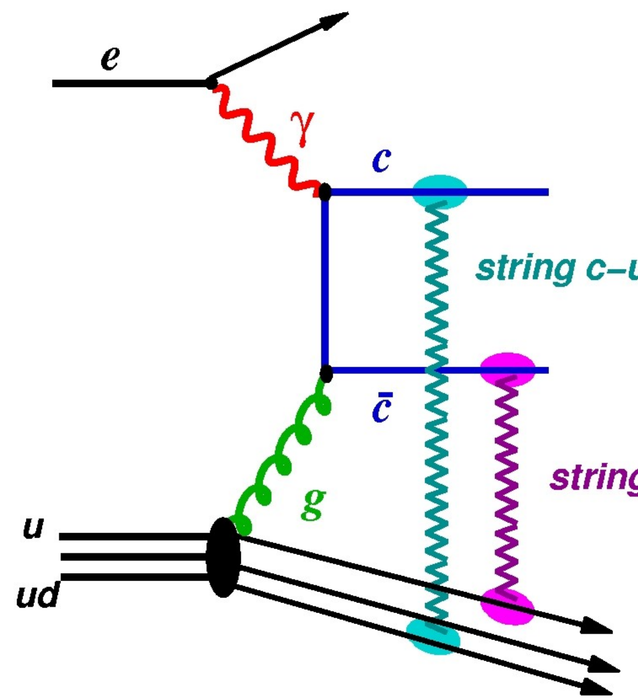
  $z = E_{D^*}/(\frac{1}{2}\sqrt{s}) = E_{D^*}/E_{BEAM}$

- 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



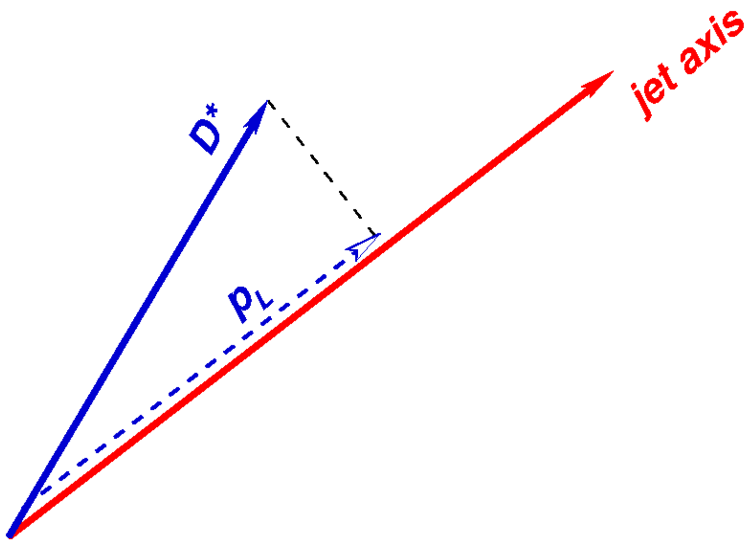
Observables for ep: Jet observable

Jet method:

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

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

- $k_\perp$-clus jet algorithm applied in γp-frame ($E_t(D^* jet) > 3$ GeV)



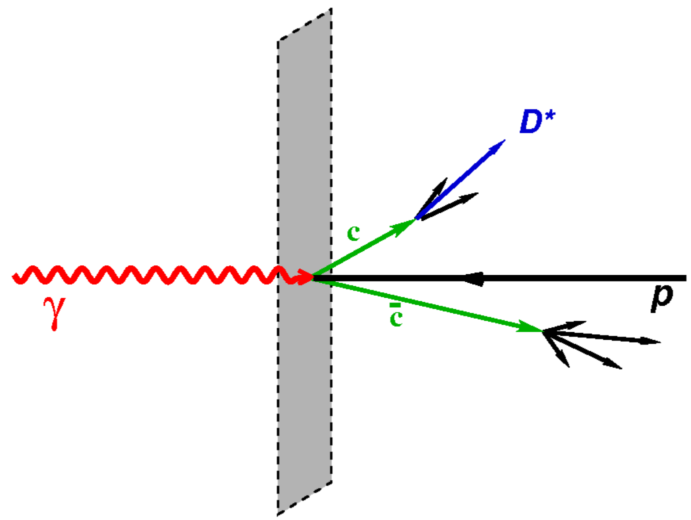
Observables for ep: Hemisphere observable

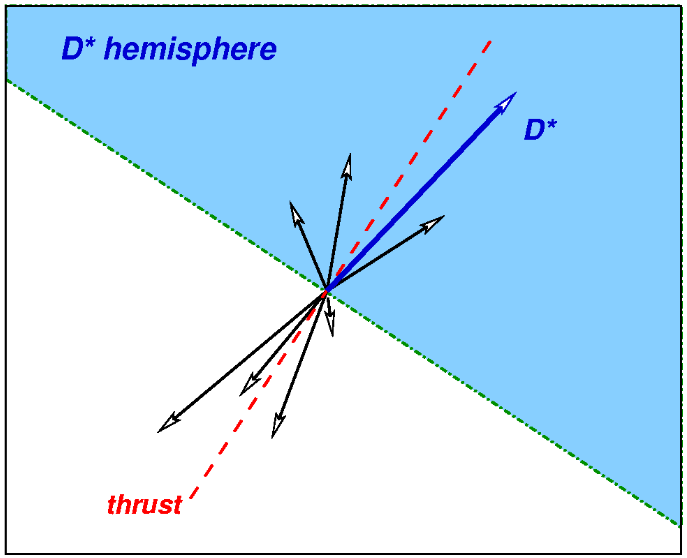
Hemisphere method:

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

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

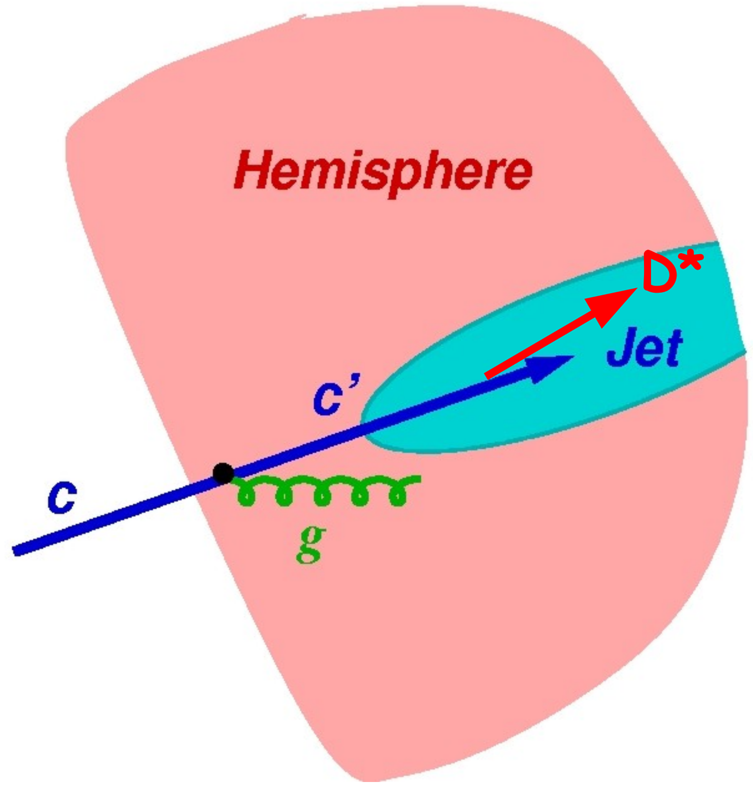
- $\eta(\text{part}) > 0$ for p-remnant suppression
- thrust axis in plane perpendicular to γ used for hemisphere division





Comparison of Observables

Hemisphere Method:



- Sums more gluon radiation than jet method
- May have different sensitivity to the hadronization process

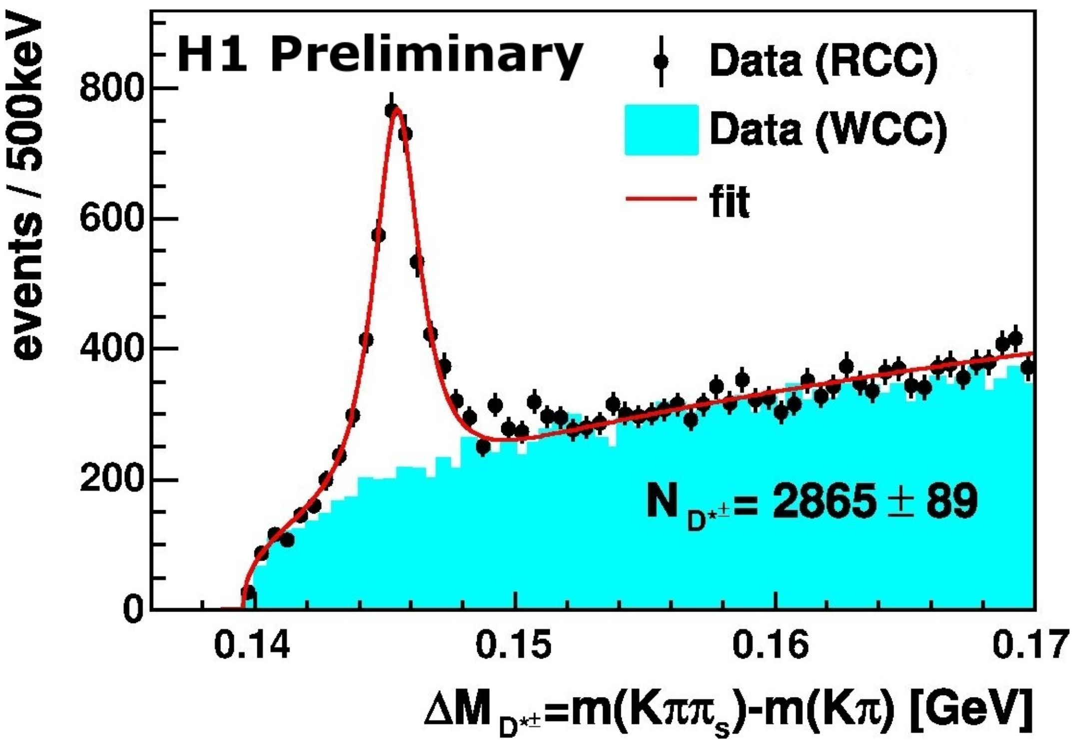
Interesting to measure both $d\sigma/z_{hem}$ and $d\sigma/z_{jet}$ because:

- 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: $D^* \to D^0\pi_s \to K\pi\pi_s$

- 99+2000 data (47 pb^{-1})
- 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
- Jet cut:
  - $E_T(D^*jet) > 3$GeV
- after E_T jet cut
  - $N(D^*) \approx 1500$

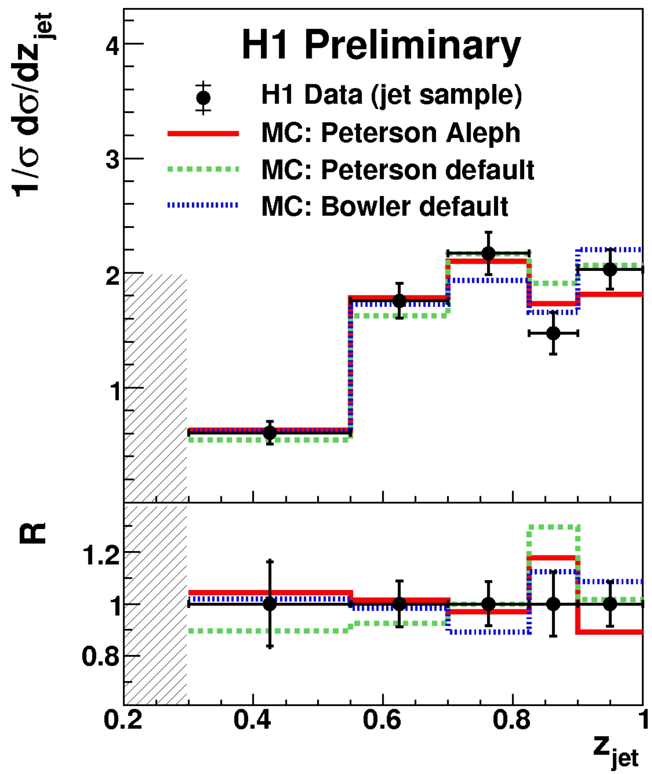


Correction Procedure

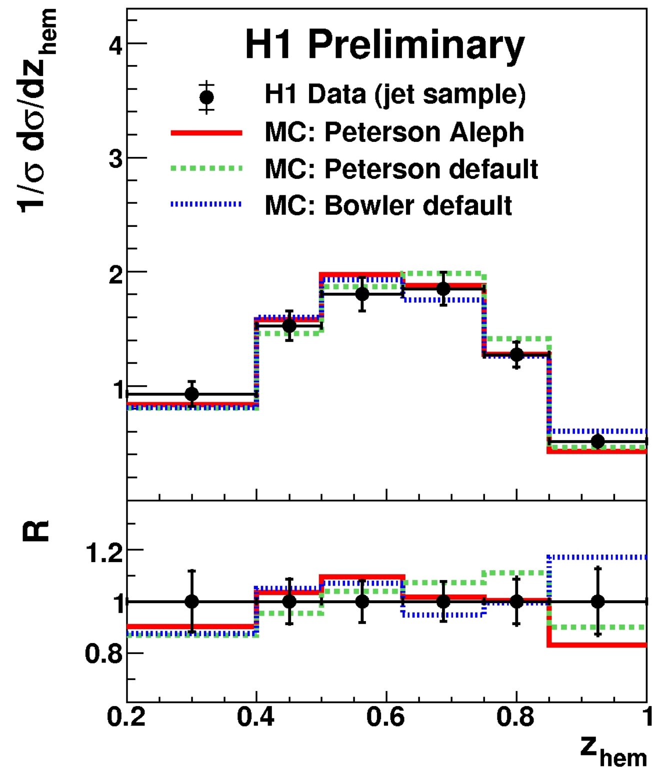
- **Subtraction of the beauty contribution to D* production**
  - using bb RAPGAP MC prediction (fraction below 2%)
- **Correcting for detector effects**
  - regularized unfolding procedure applied, migrations from one bin into another one taken into account by detector response matrix
- **QED radiative 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:** includes ~27% of D*s coming from higher resonances (c->D**->D*), ε=0.04

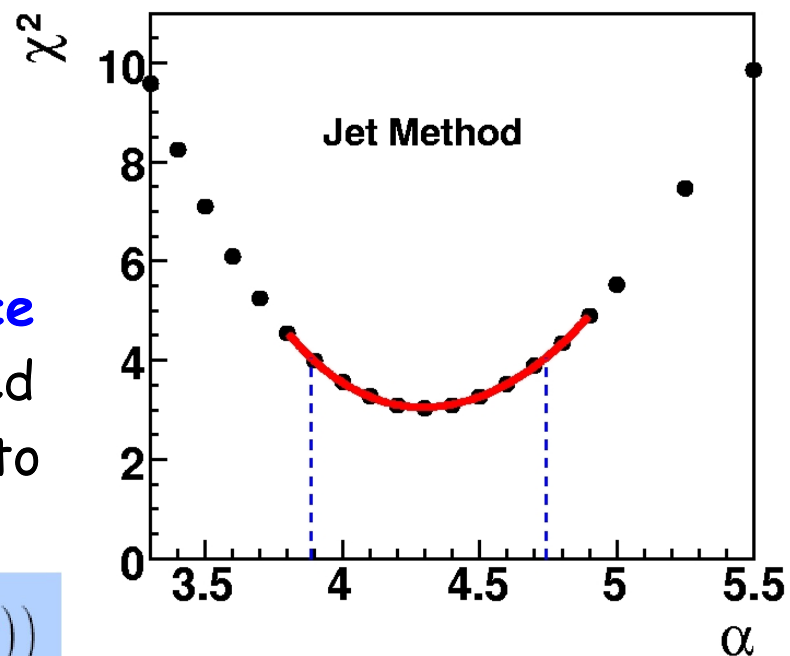
- Reasonable description of the data by models

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)

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

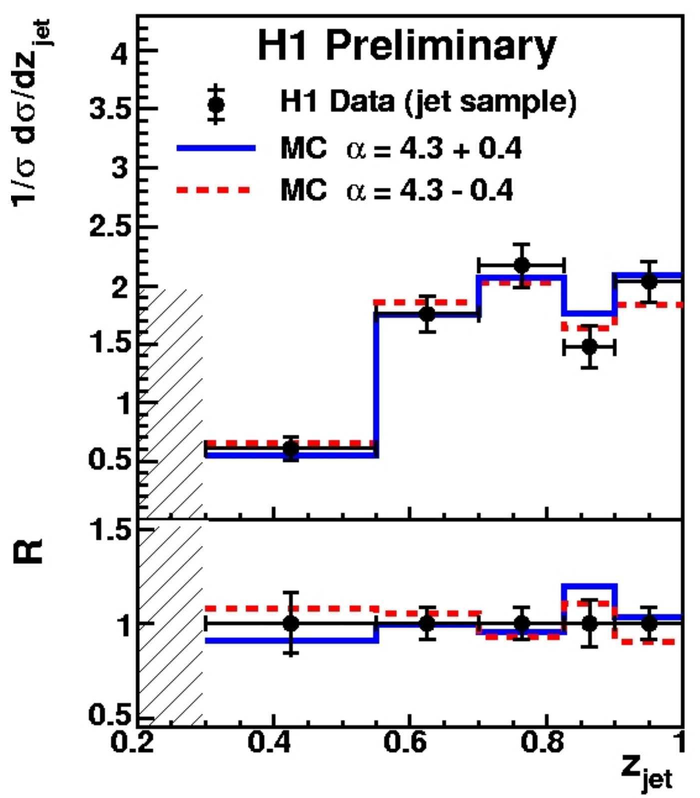


Extracted FF Plots - MC

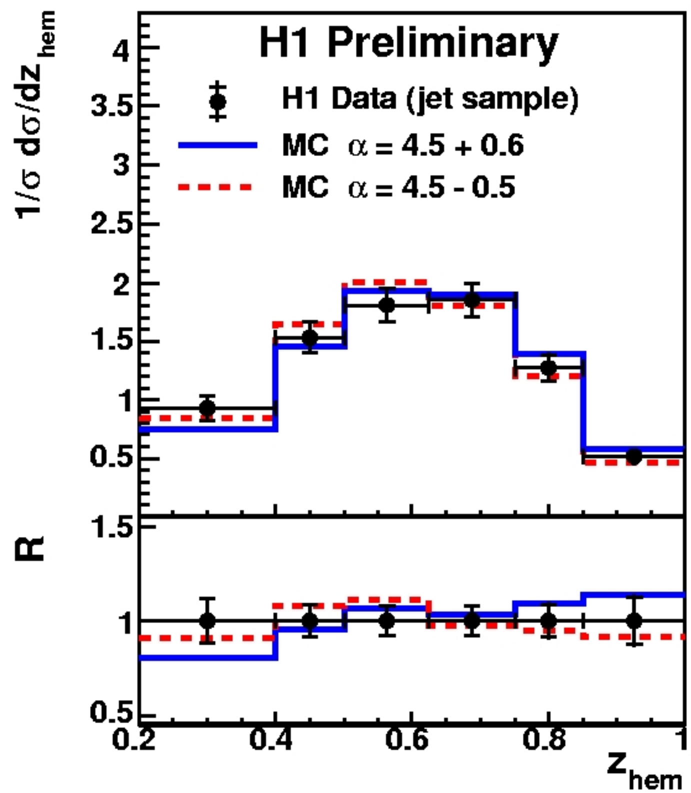
Rapgap with Aleph setting & Kartvelishvili parametrization:

(best fit +/- 1σ error shown)

Jet method



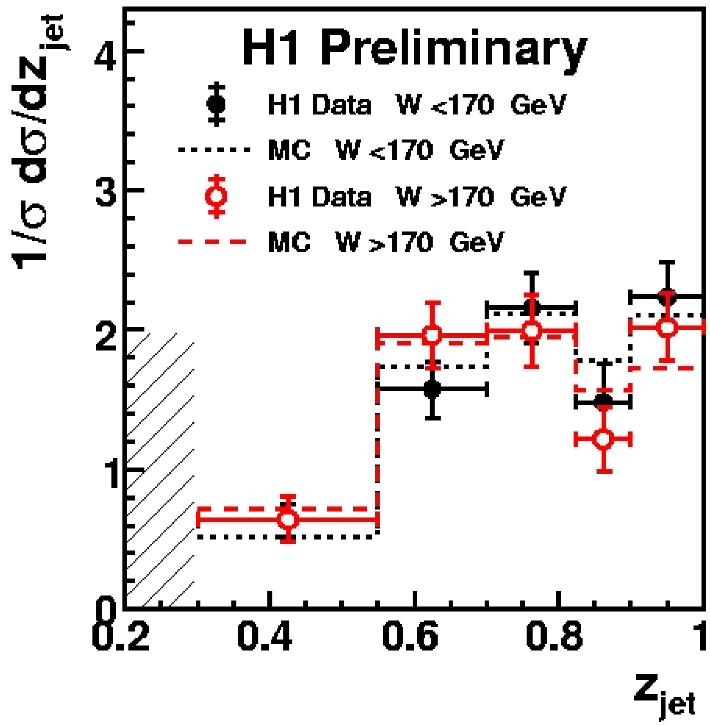
Hemisphere method



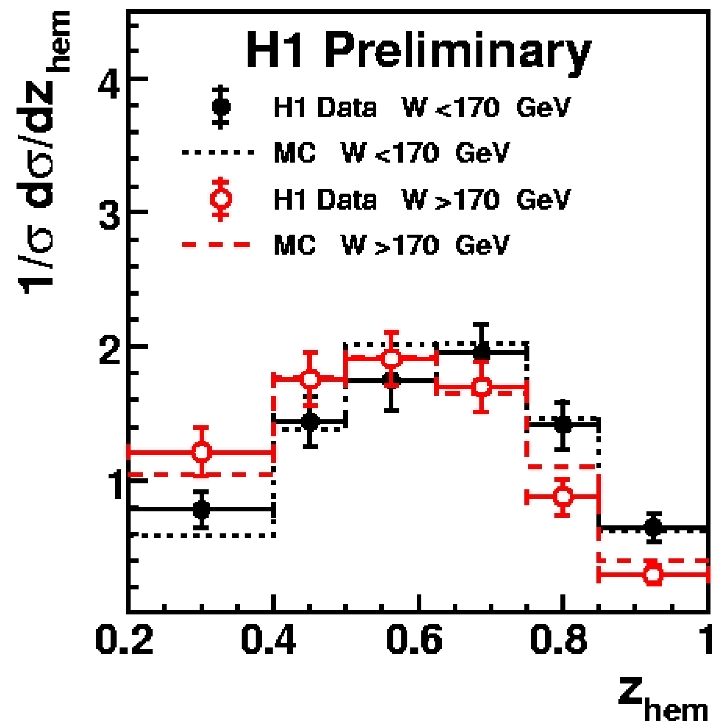
- The data are well described by tuned models (both Peterson and Kartvelishvili
- both methods agree well with each other within errors

Observables as Function of W

Jet method



Hemisphere method



- 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

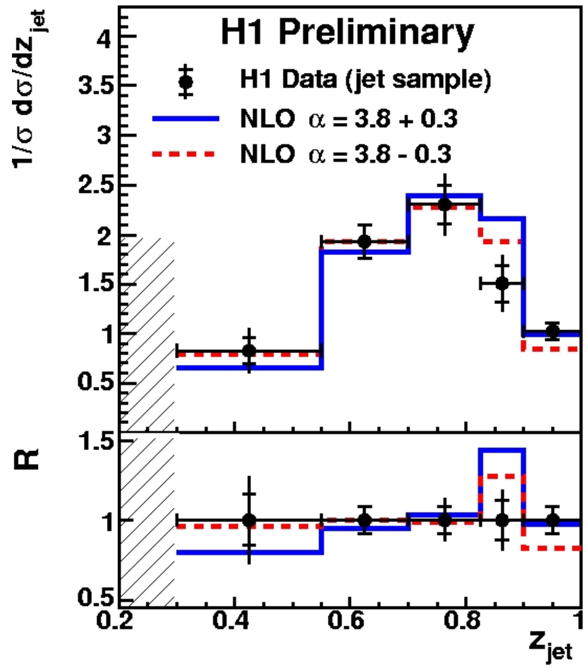
Extracted FF Plots - NLO

HVQDIS: massive NLO calculation

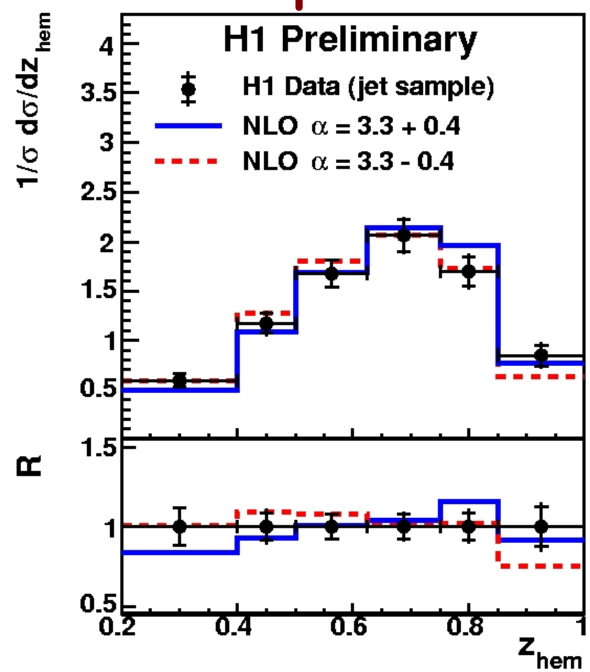
(m_c=1.5 GeV, $\mu_r=\mu_f=\sqrt{(Q^2+4m_c^2)}$, proton PDF= CTEQ5F3)

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

Jet method



Hemisphere method



- **Peterson fails to describe the data**
- **Reasonable description in case of Kartvelishvili**

Investigating the Threshold Region

- events not fulfilling hard scale cut E_T(D*jet)>3GeV (~1300 D* events, big part of c cross cection!)

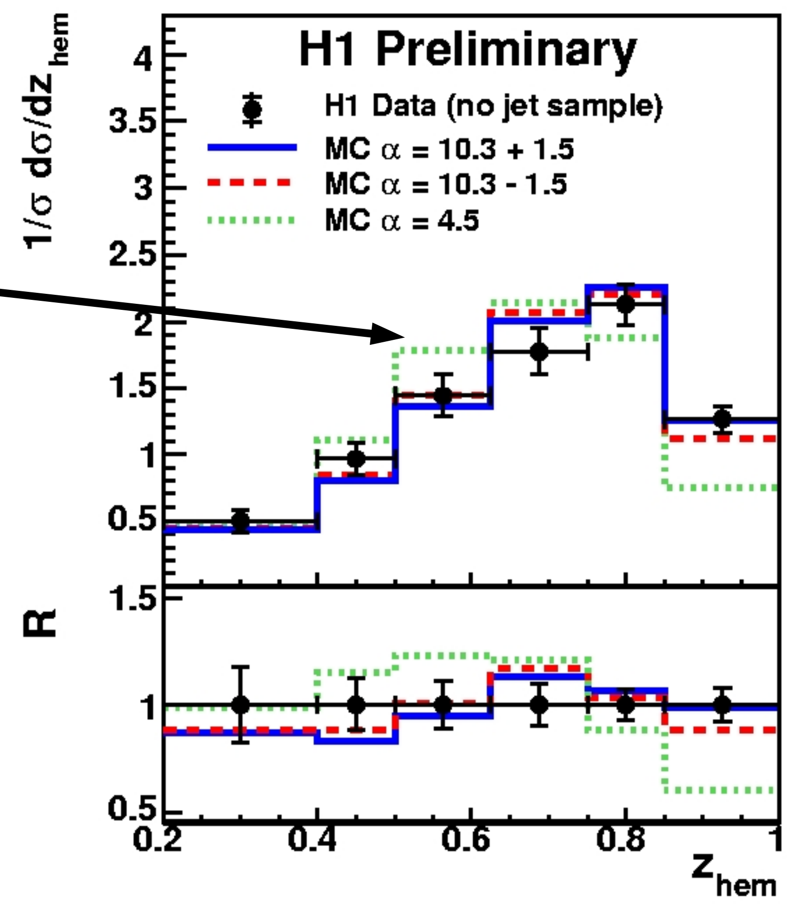
  => hemisphere method can be used

- 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:



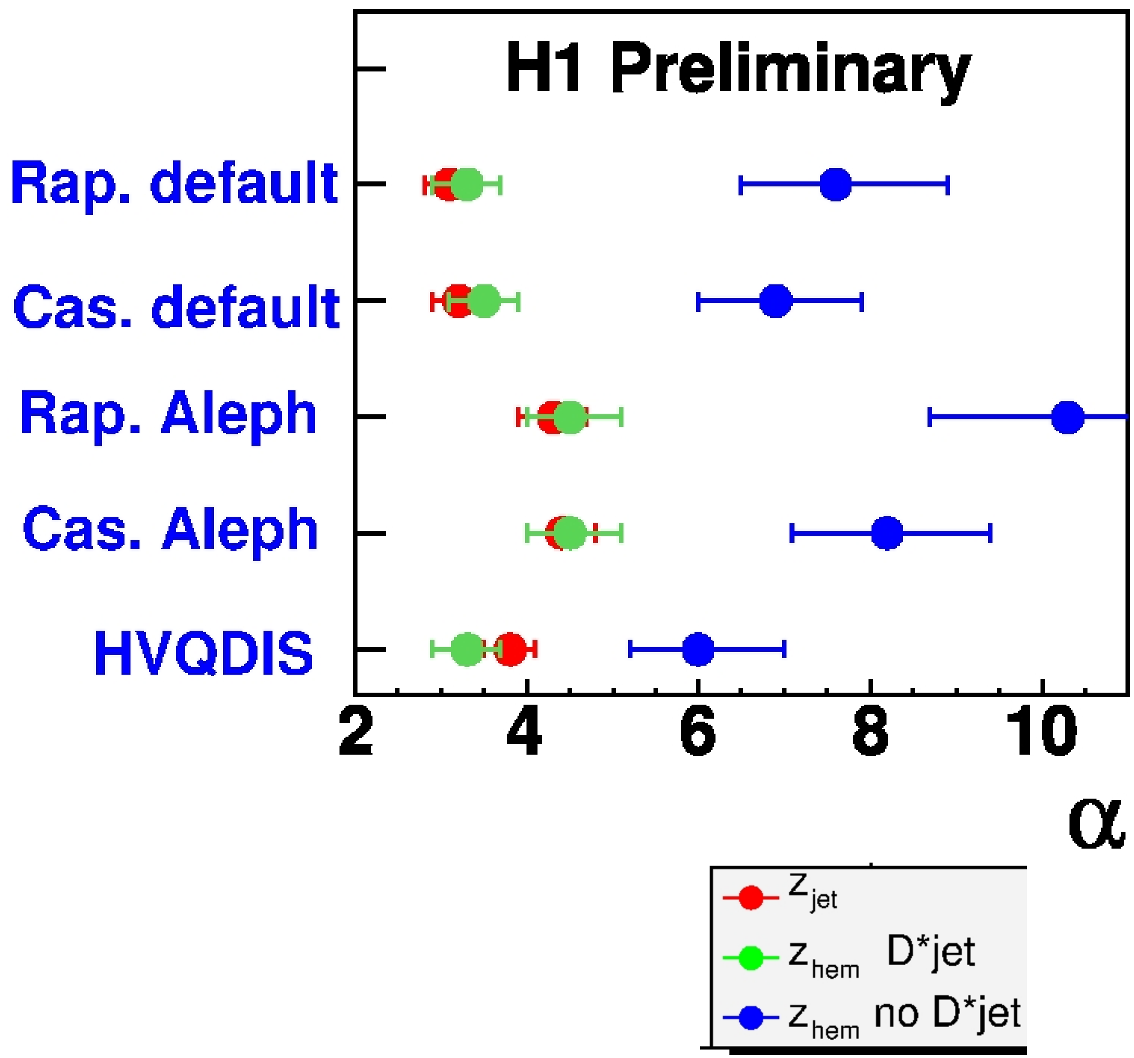
FF Parameter Fit Results (Summary)

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

- Sample of events without D* jet needs different FF!

Kartvelishvili



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
- **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}:**
  - Needs different FF then basic sample
  - NLO (HVQDIS) fails completely
- **We don't get a consistent picture of charm fragmentation over full phase space**

Conclusions II

Need more input from both theory and experiment!

Backup slides

RAPGAP with PYTHIA		hemisphere observable	jet observable
parameter settings	fragmentation function	(χ^2/n.d.f.)	(χ^2/n.d.f.)
Aleph	Peterson $\varepsilon = 0.04$	6.0/5	4.3/4
default	Peterson $\varepsilon = 0.05$	6.1/5	6.0/4
default	Bowler $a = 0.3, b = 0.58$	5.6/5	3.5/4

Data compared with default MC models

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 **γ**p frame $p_L(D^*)$ generated according to given parametrization (D* put on mass shell)