Charm Production at HERA-I and Heavy Flavours at HERA-II

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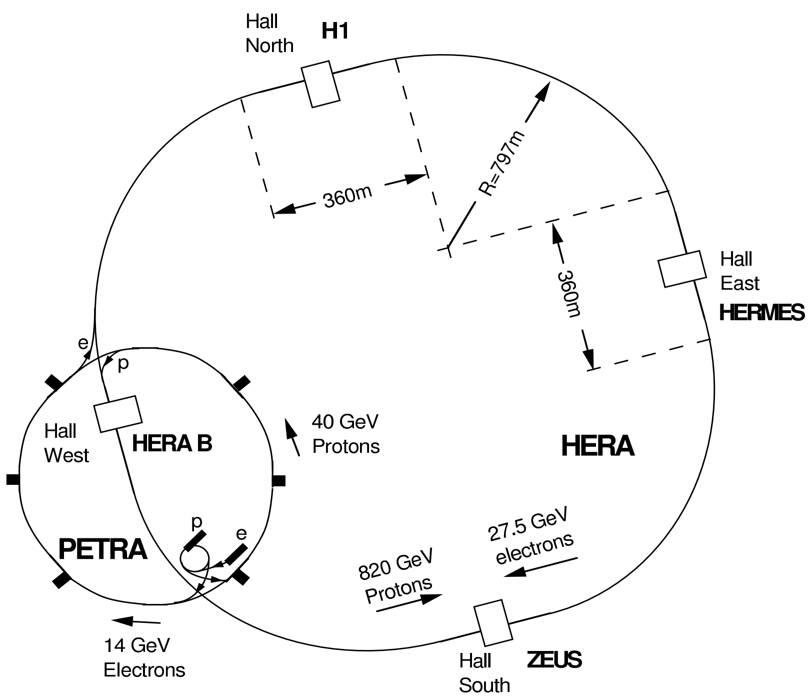
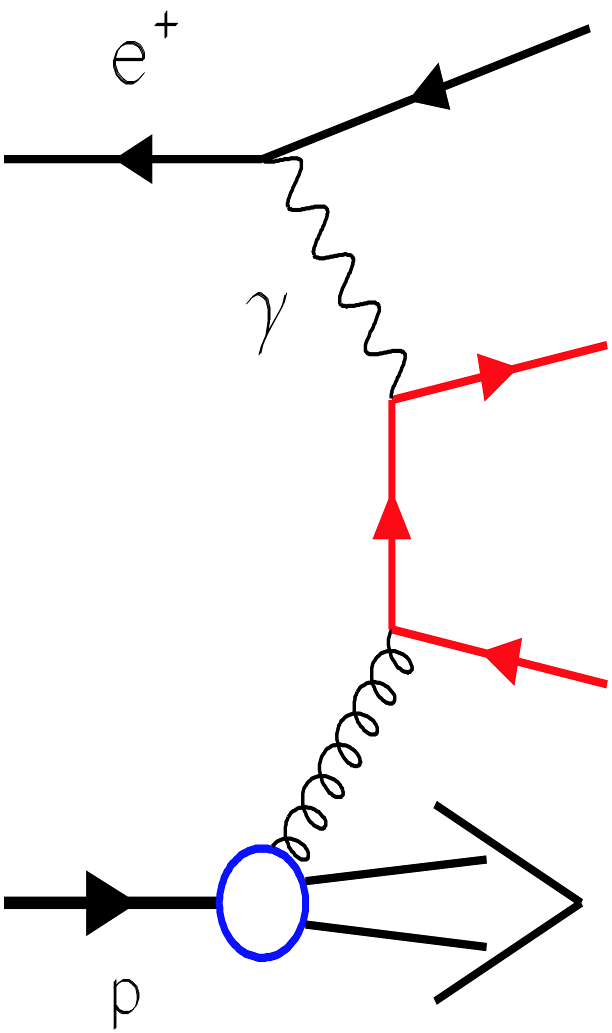


Open charm production in ep scattering



- Hard process

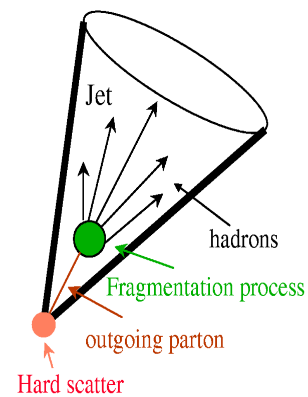
  e.g. Boson-Gluon Fusion (BGF) $\gamma g \rightarrow c\bar{c}$
- Test pQCD, probe gluon in proton

  Parton shower development
- Final-State parton $\rightarrow$ hadron transition

  Hadronisation, Fragmentation
- Two kinematic regimes:

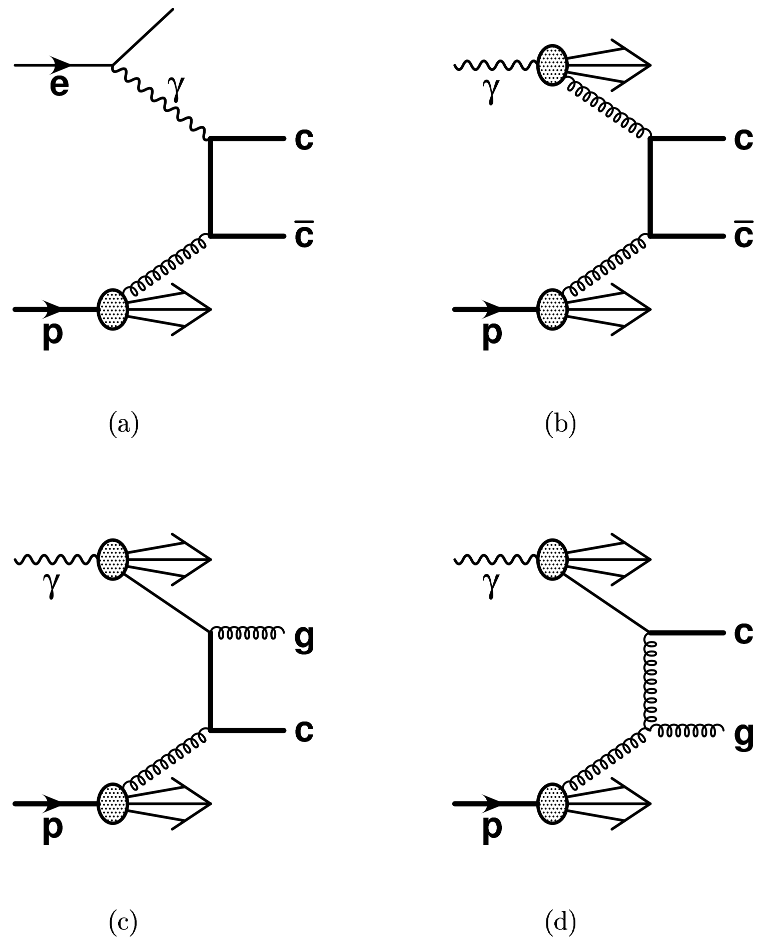
  Deep Inelastic Scattering (DIS)$Q^2 > 1$ GeV^2

  Photoproduction (PHP) $Q^2 < 1$ GeV^2



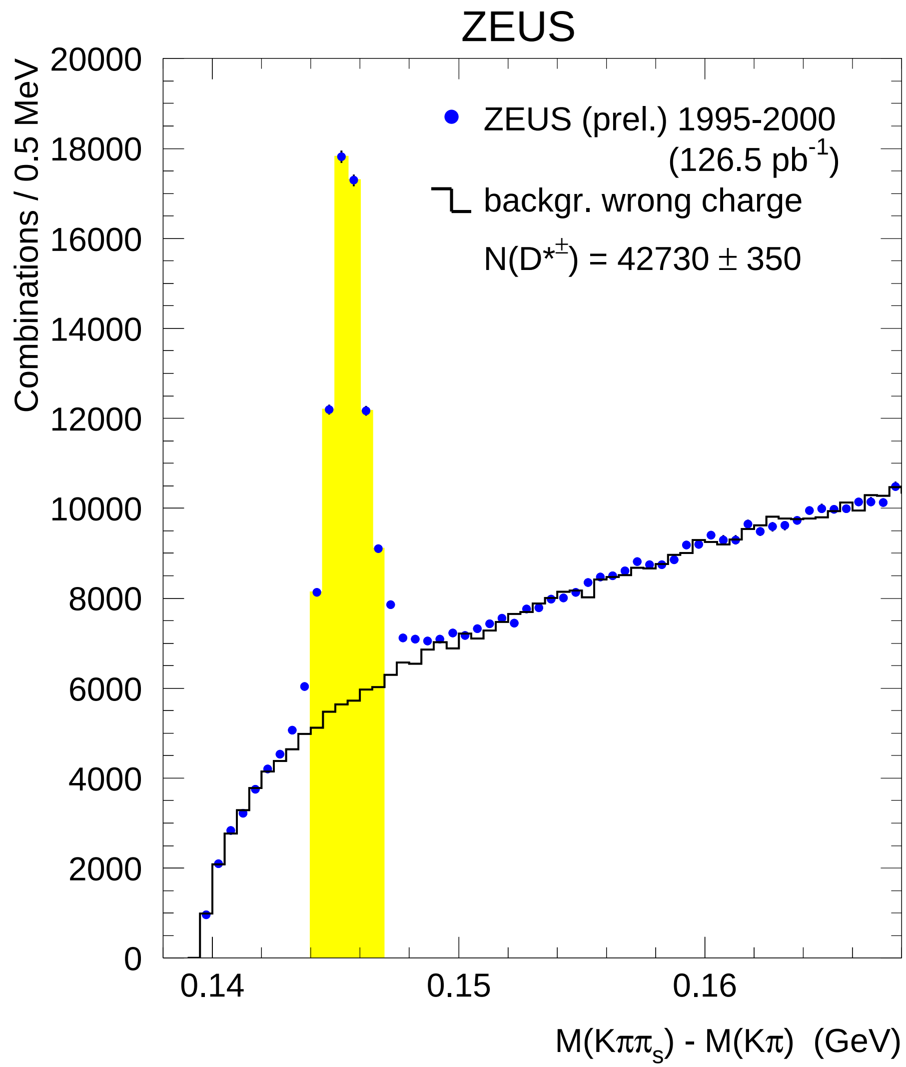
Theoretical Models for charm production at HERA

- The main contributing processes to Heavy Flavour production (Leading Order) :
  (a) BGF (Boson Gluon Fusion)
  'Direct Process' point like photon(γ).
  'Resolved-γ Process'
  (b) is Hadron like,(c) c-Excitation &
  q-Propagator,(d) g-Propagator.
- Next-to-Leading order (NLO) calculations:
  'massive' scheme, fixed order NLO
  valid for $p_t \sim m_q$ (Frixione et al.)
  'massless' scheme, re-summed NLL
  charm in γ or proton $p_t >> m_q$ (Kniehl et al.)
- Fragmentation: non-perturbative models
  e.g. Peterson fragmentation



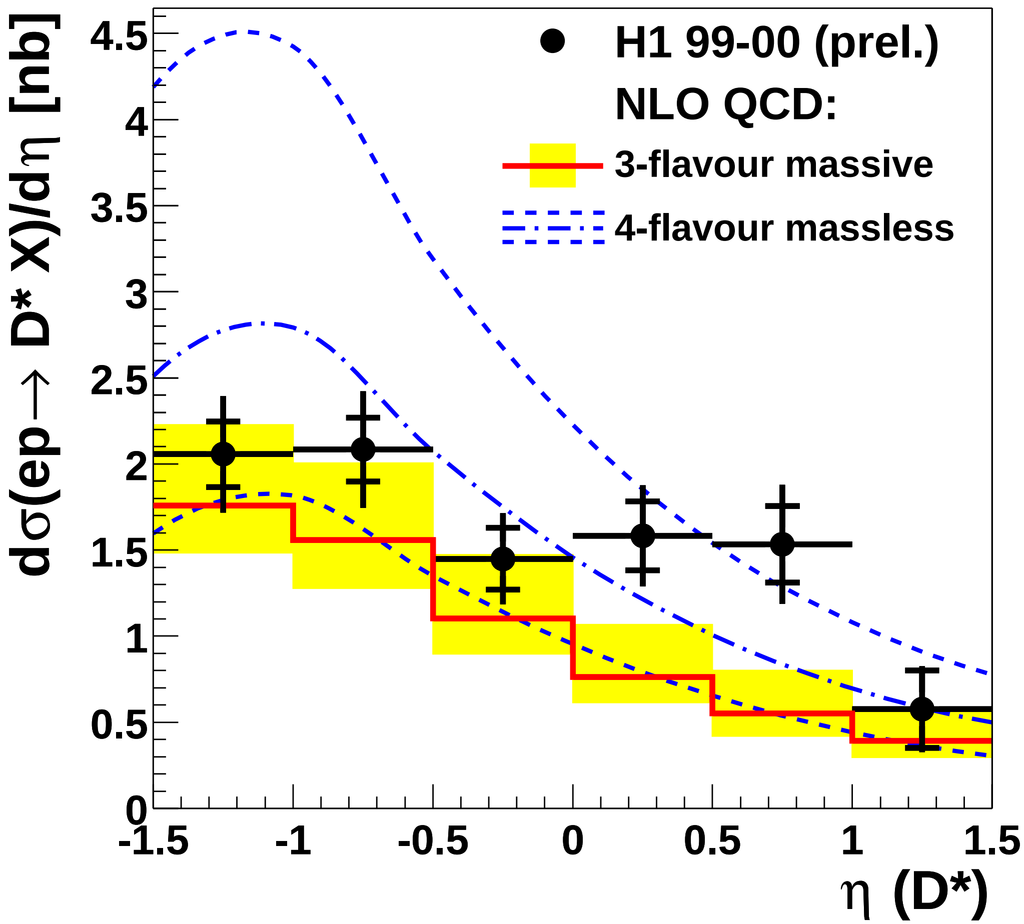
Charm Tagging

- Charm is tagged at HERA most efficiently in the 'golden' decay channel $D^{*\pm} \rightarrow K^{\mp} \pi^{\pm} \pi_s^{\pm}$.
- Mass difference method: $\Delta M = M(D^*) - M(D^0)$



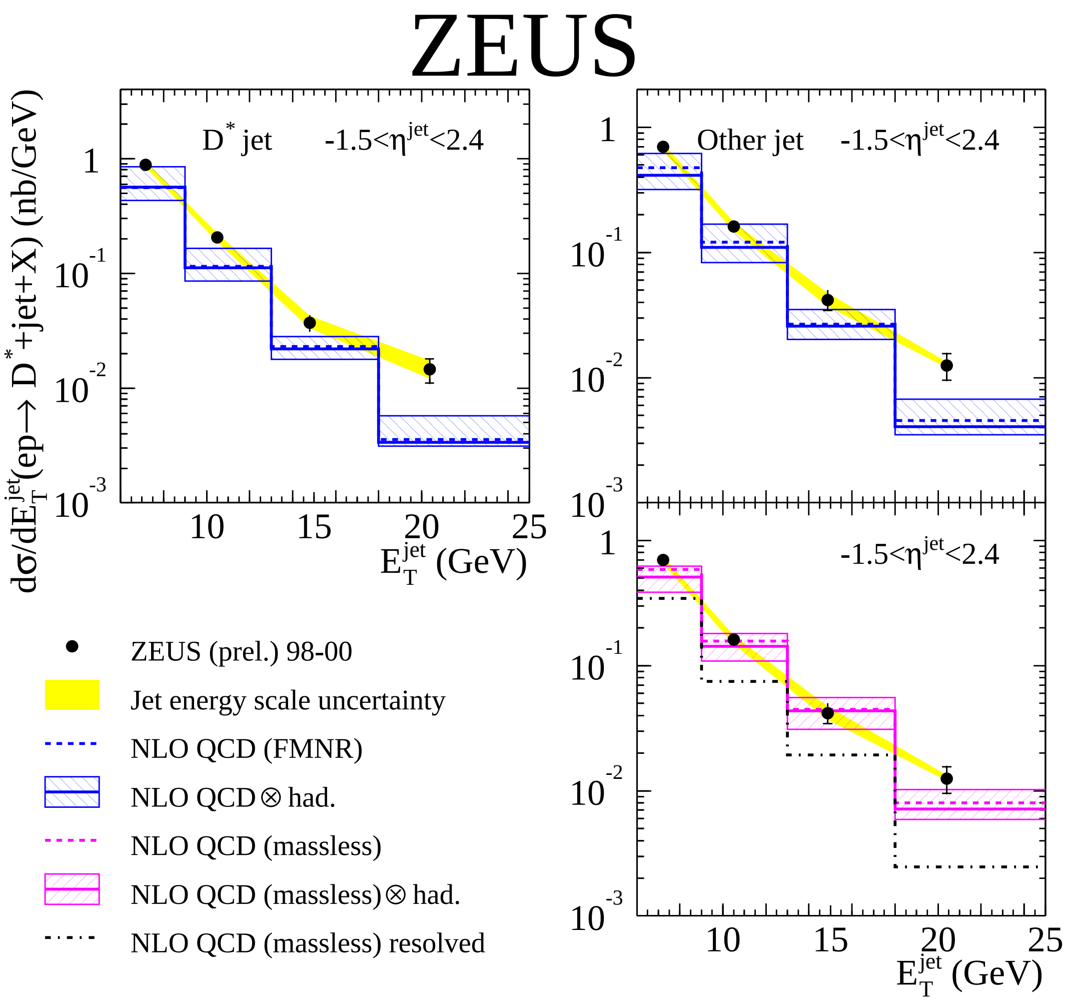
Photoproduction of $D^{*\pm}$ mesons at HERA

- ‘Massive’ NLO calculation and ‘Massless’ NLO both fail in describing the shape.
- Theories have large uncertainties
- Measurements are able to constrain theories significantly



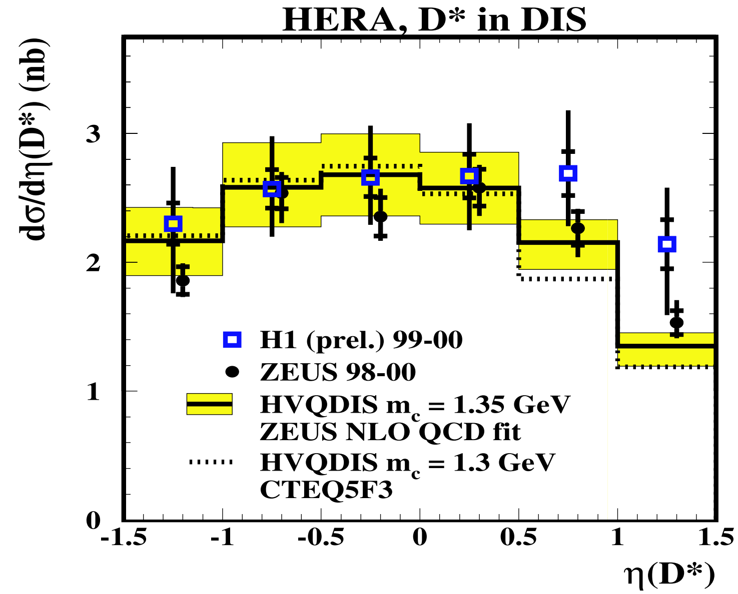
$D^{*\pm}$ Photoproduction Inclusive jet cross sections

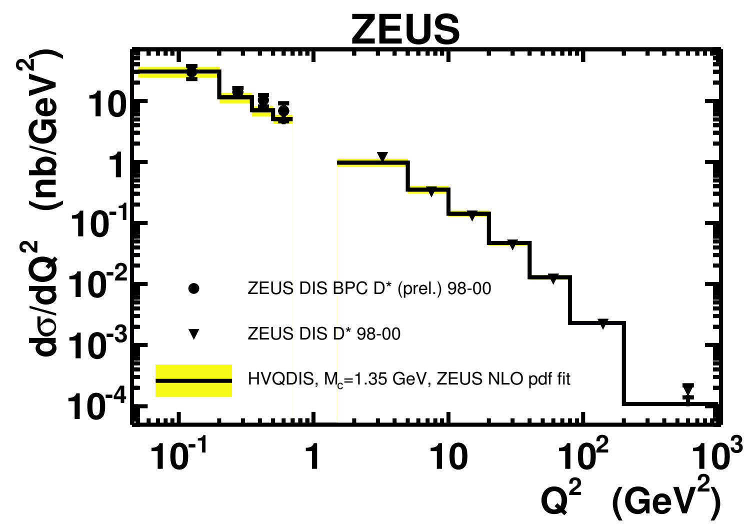
- Additional scale added E_T^{jet}
- 'Massive' NLO calculation below data at high E_T^{jet}
- 'Massless' NLO calculation in reasonable agreement with data
- Theories have large uncertainties



Differential cross sections in DIS

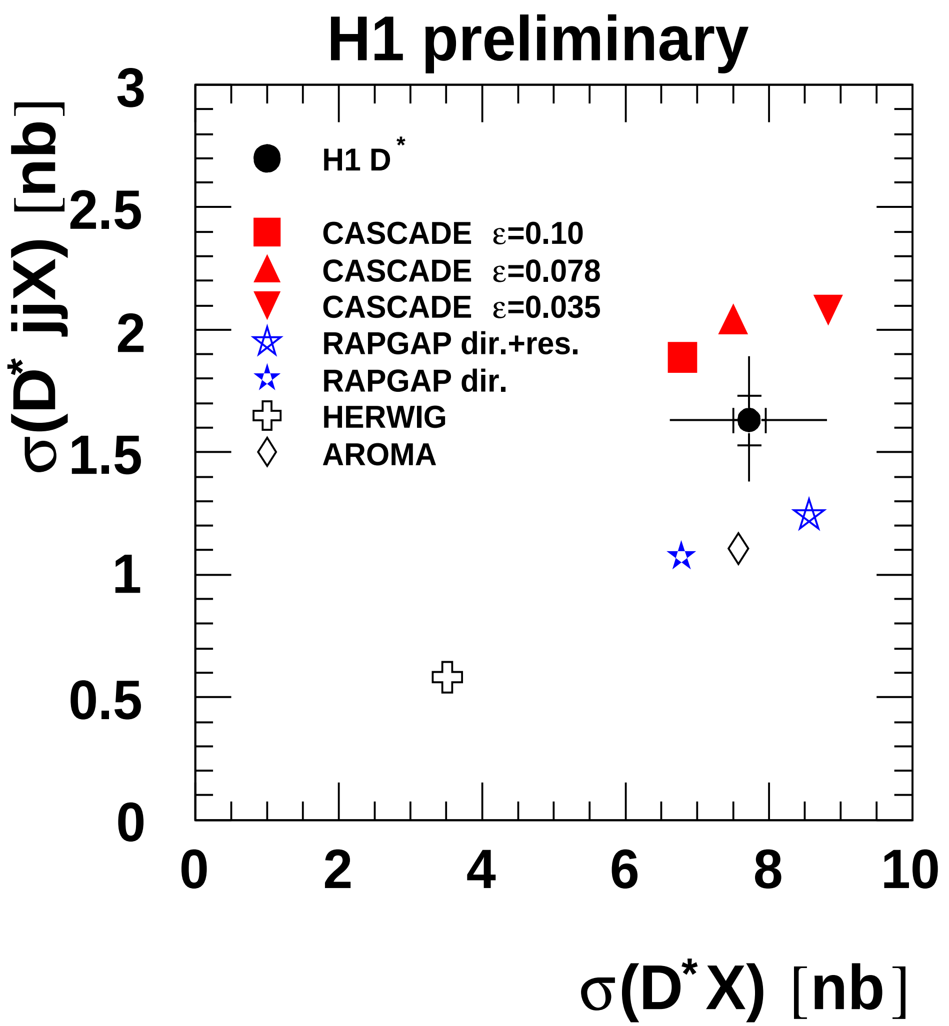
- Data in good agreement with NLO calculations, down to low Q^2
- Theoretical uncertainties due to:
- Proton PDF
- charm mass
- renormalization/factorisation scale
- fragmentation
- Theoretical uncertainty larger than Experimental uncertainty





Inclusive $D^{*\pm}$ meson and Associated Dijet Production in DIS

- Use of additional scales Q^2 and E_T^{jet}
- Inclusive $D^{*\pm}$ meson production is well described by Rapgap and CCFM model CASCADE
- Discrepancy between models and with data.



Charm Contribution to proton structure function F_2

Extraction of (extrapolation to) $F_2^{c\bar{c}}$

The ratio $F_2^{c\bar{c}}/F_2$ rises from 10% to 30%

as Q^2 increases and x decreases

At low Q^2 errors are comparable to

those from PDF fit

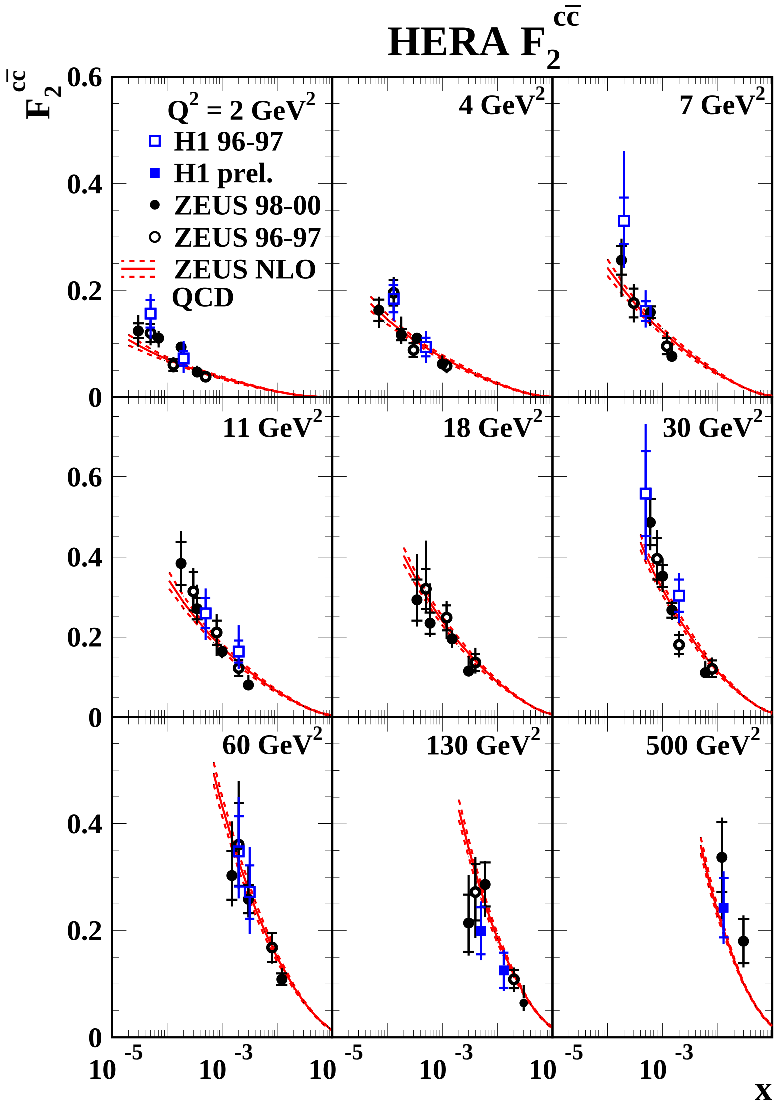
→ use cross sections

in future fits to additionally

constrain the gluon density

New H1 points at high Q^2, (also $F_2^{b\bar{b}}$)

→ see talk by A.Meyer



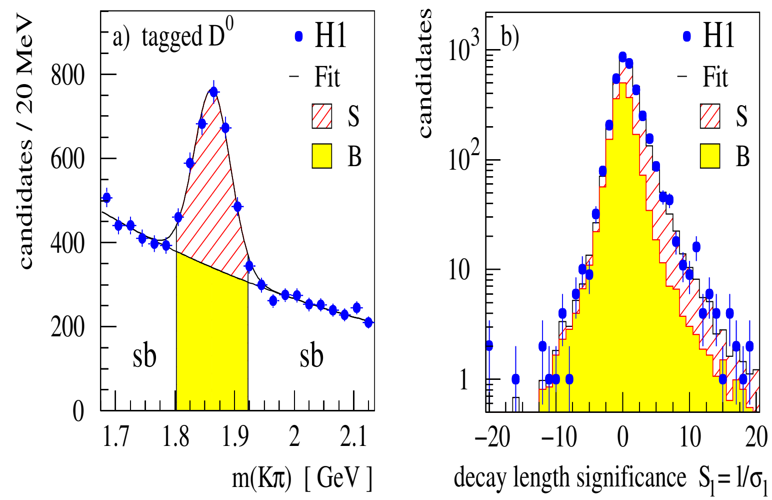
Charm Tagging Methods

Charm tagging via decay length

Reconstruct charm hadrons via secondary vertex

H1 central silicon tracker (CST):

reduced via decay length significance $S_l = l/\sigma_l$



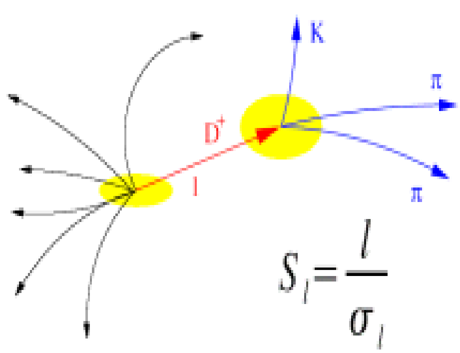
other charm signals:

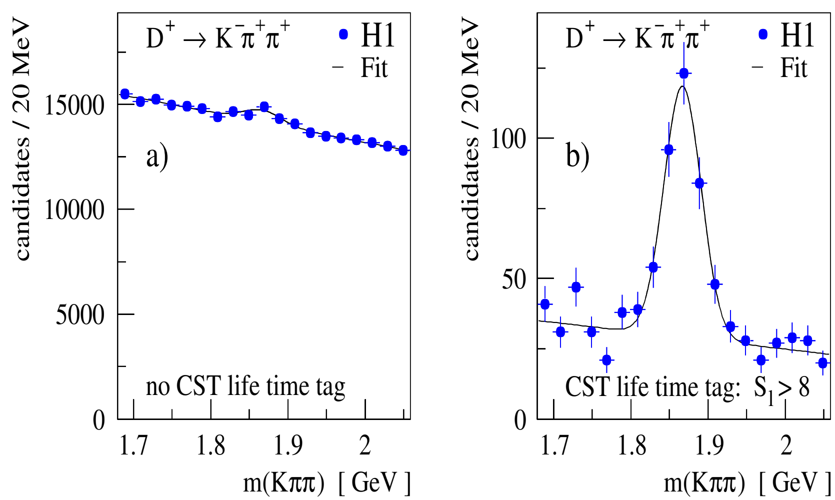
$D^* \to D^0\pi_s \to (K^-\pi^+\pi^+\pi-)\pi_s$

$D^0 \to K^-\pi^+$ untagged

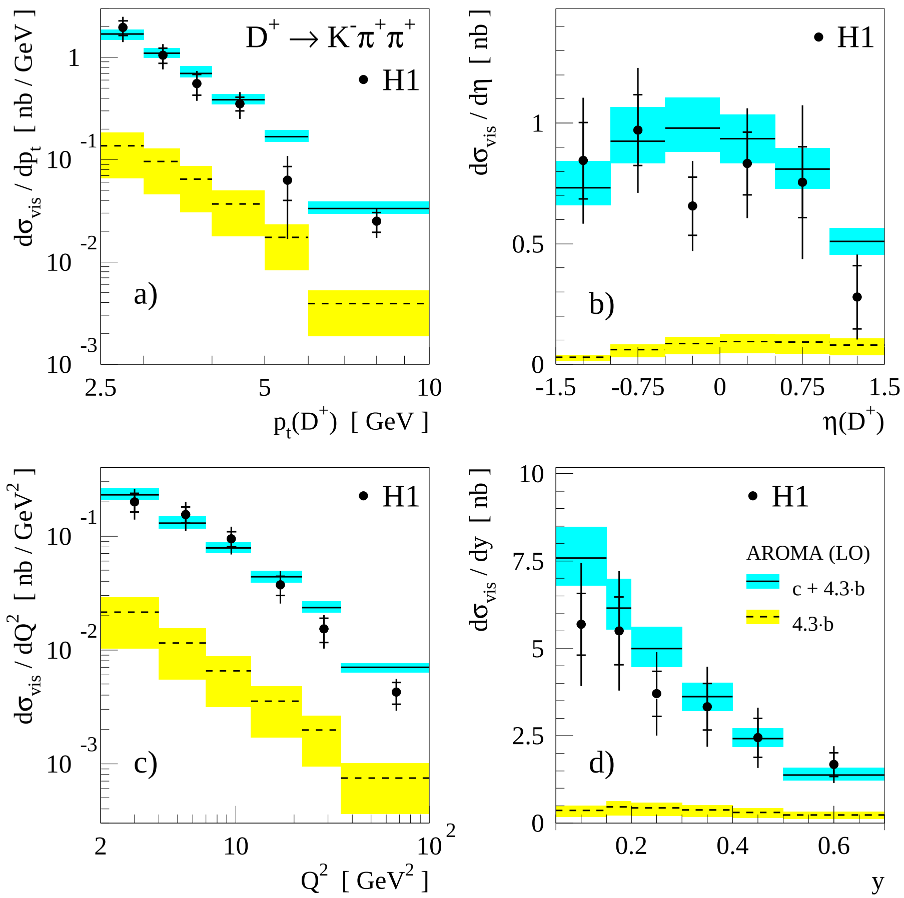
$D^+ \to K^-\pi^+\pi^+$

$D_s \to \phi\pi \to (K^-K^+)\pi$



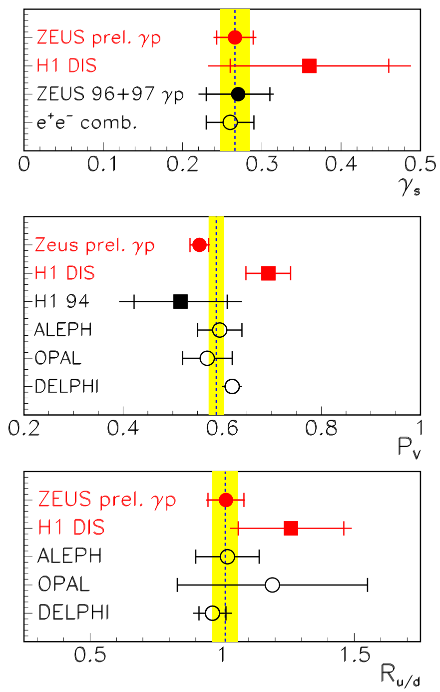


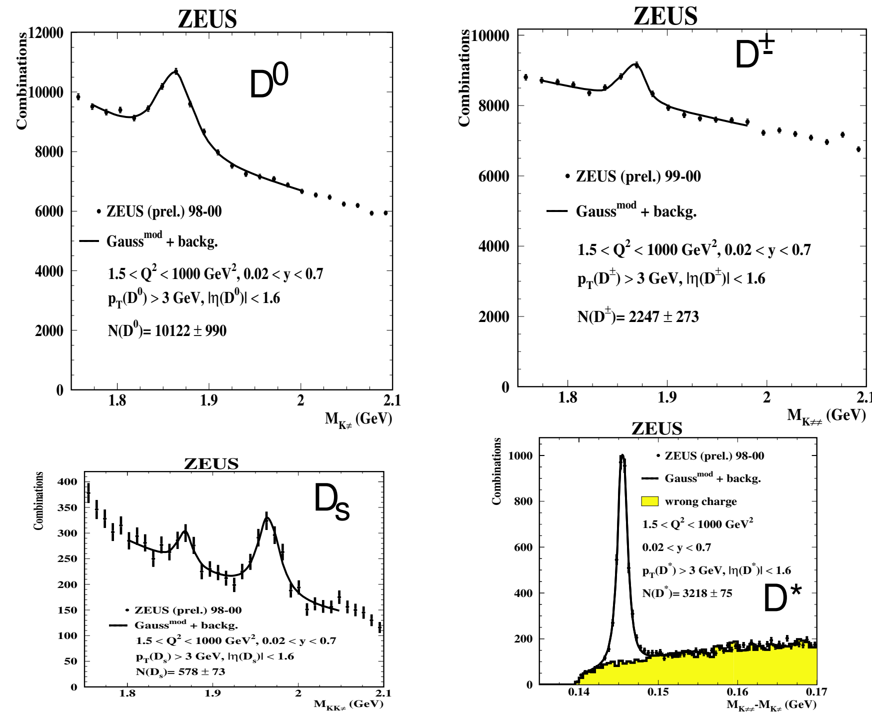
D meson Production in DIS



Normalisation and shapes agree well with LO+PS (AROMA)

Total D meson in DIS cross sections





Fragmentation sensitive parameters, P_V, $R_{u/d}$ and γ_s are extracted and compare favourably with world averages.

	ZEUS	HVQDIS pQCD
$\sigma(e^{\pm}p \to e^{\pm}D^0X)$	$7.44 \pm 0.78^{+0.29}_{-0.49}$nb	7.14nb
$\sigma(e^{\pm}p \to e^{\pm}D^{\pm}X)$	$2.42 \pm 0.30^{+0.21}_{-0.06}$nb	3.02nb
$\sigma(e^{\pm}p \to e^{\pm}D_sX)$	$2.25 \pm 0.30^{+0.09}_{-0.33}$nb	1.32nb
$\sigma(e^{\pm}p \to e^{\pm}D^{*\pm}X)$	$3.22 \pm 0.08^{+0.07}_{-0.05}$nb	3.06nb

Charm Fragmentation Fractions/Ratios

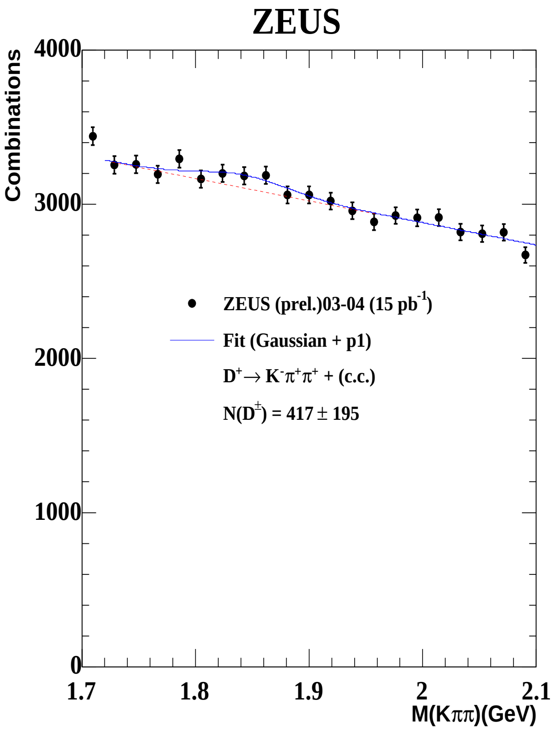
- Cross sections $D^{*\pm}, D^0, D^{\pm}, D_s$

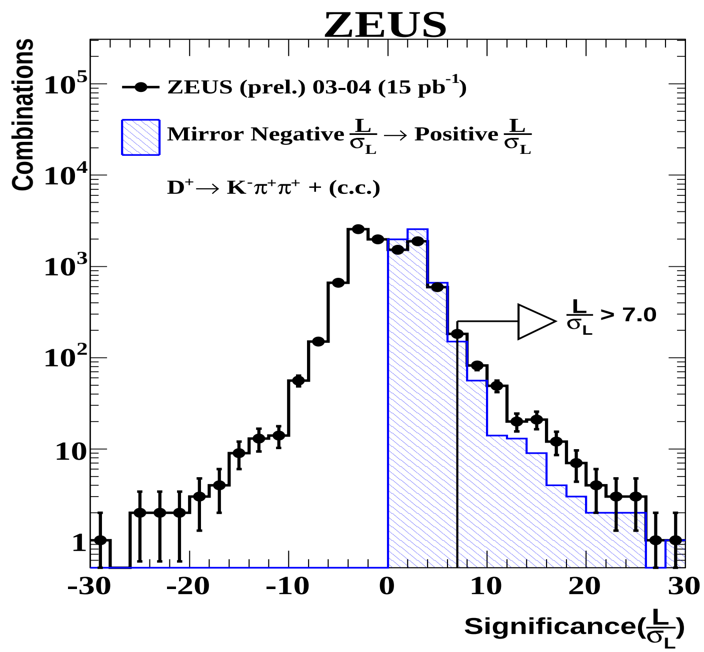
  $\longrightarrow$ fragmentation fractions.

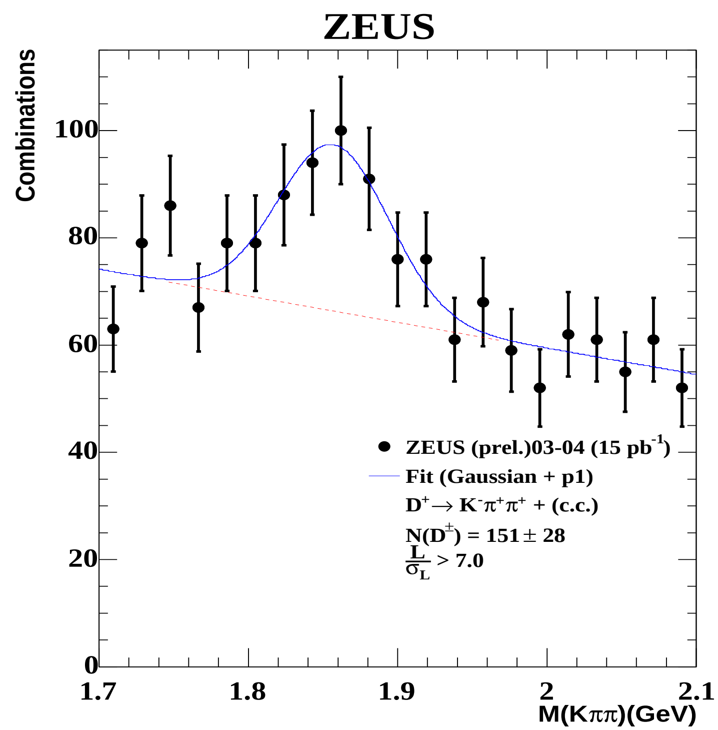
	H1	ZEUS(prel.)	e^+e^-
$f(c \to D^+)$	0.203 ± 0.026	$0.249 \pm 0.014^{+0.004}_{-0.008}$	0.232 ± 0.018
$f(c \to D^0)$	0.560 ± 0.046	$0.557 \pm 0.019^{+0.005}_{-0.013}$	0.549 ± 0.026
$f(c \to D_s^+)$	0.151 ± 0.055	$0.107 \pm 0.009^{+0.005}_{-0.005}$	0.101 ± 0.027
$f(c \to D^{*+})$	0.263 ± 0.032	$0.223 \pm 0.009^{+0.003}_{-0.005}$	0.235 ± 0.010
$f(c \to \Lambda_c^+)$		$0.076 \pm 0.020^{+0.017}_{-0.001}$	0.076 ± 0.007

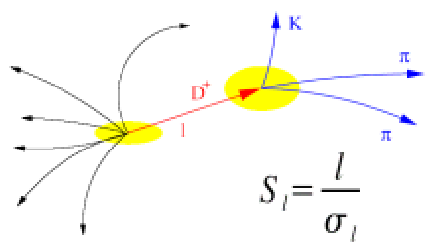
Charm fragmentation fractions are universal

D meson Tagging at HERA II









Lifetime tagging at ZEUS → potential for the future

First Look at HERA II Data

Beauty tagging via impact parameter

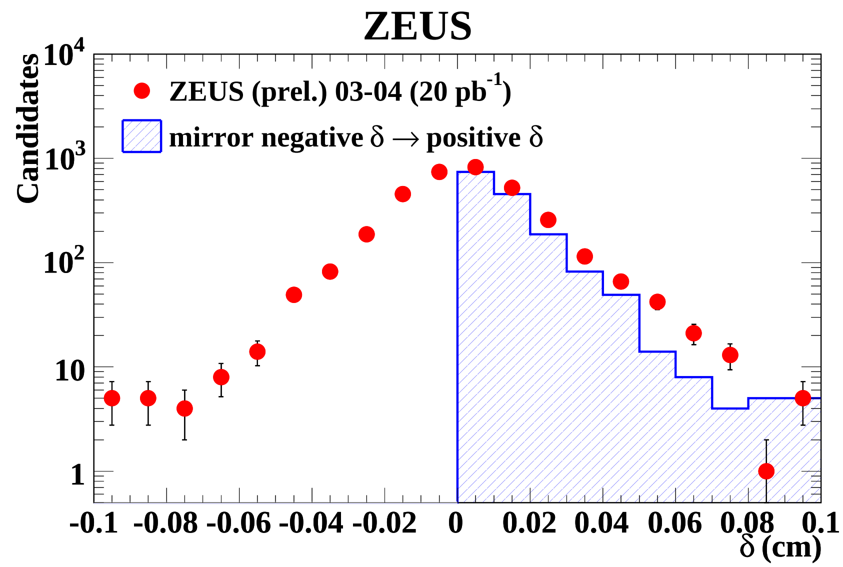
Semi-leptonic muon decays of beauty quarks

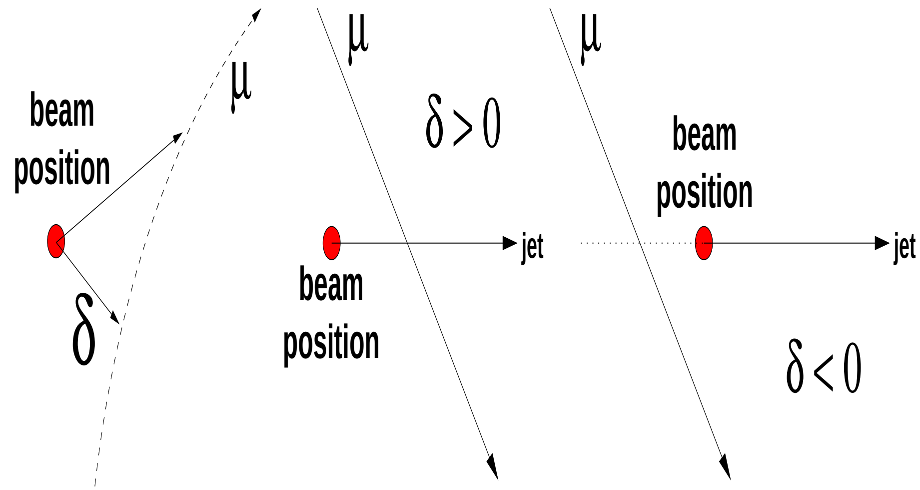
Collecting new quality data,

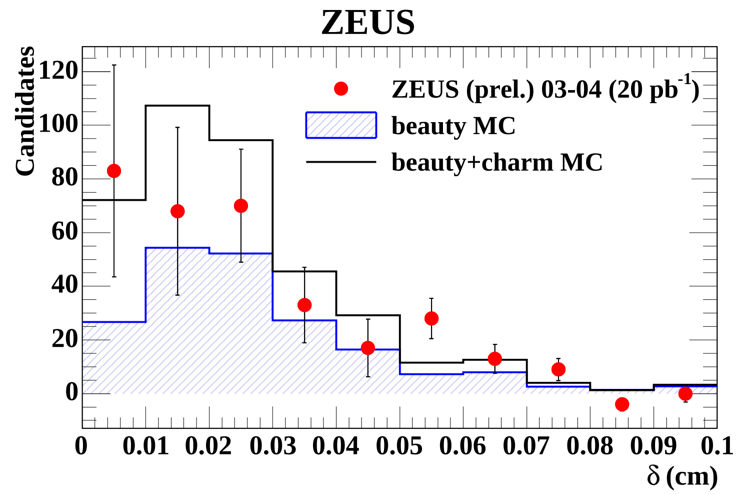
New detectors working well!

→ more on HERA beauty production

see A.Meyers talk







Summary & Outlook

- Charm cross sections measured are generally well described pQCD.

  $\longrightarrow$ charm cross sections well understood
- Charm PHP and jets showing the need for 'massless' calculations

  $\longrightarrow$ future scope to be included in PDF fits
- Experimental errors typically smaller then theoretical uncertainties

  $\longrightarrow$ more theoretical developments needed.
- Fragmentation fractions measured in γp and DIS $\rightarrow$ competitive precision

  Evidence that charm fragmentation is universal in e^+e^- and ep
- HERA II $\longrightarrow$ will provide more precise measurements with increased luminosity, improved instrumentation.
- First look at new Data with improved instrumentation shows that lifetime tagging with new ZEUS vertex detector works as expected.

Expect a lot more charm from HERA II

First Look at HERA II Data

ZEUS beauty candidate event 2 Jets and 2 associated muons

Impact parameters relative to the beam spot of 250 and 330 μm