Charm production and F_2^c at HERA

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on behalf of
the H1 and ZEUS collaborations

at DIS 2002 Cracow

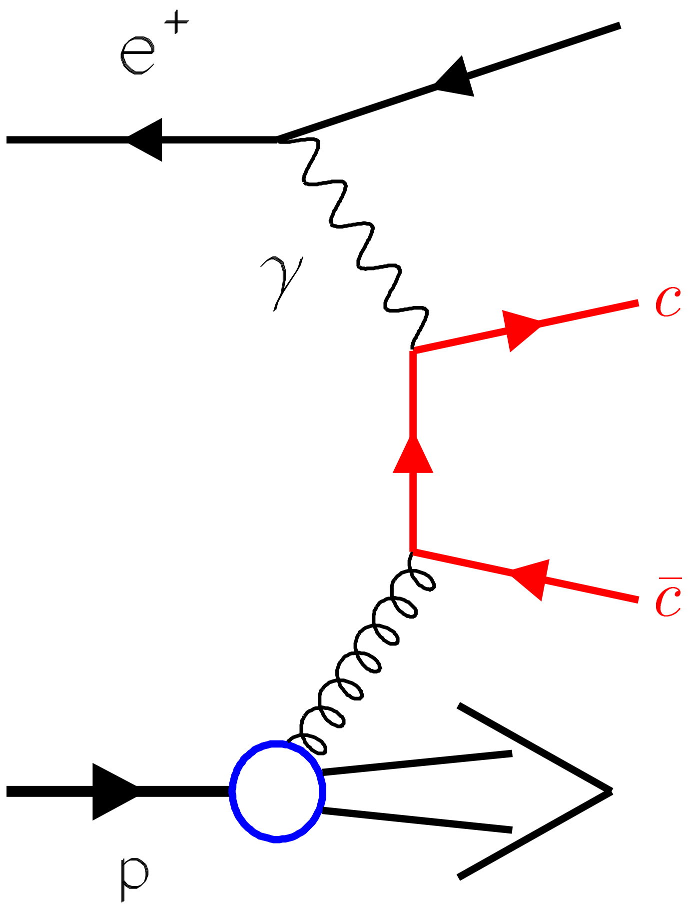
Theory

Experimental results

Conclusions

Theory

Dominant process is BGF



$\Rightarrow$ Driven by gluon in proton

Why is it of interest?

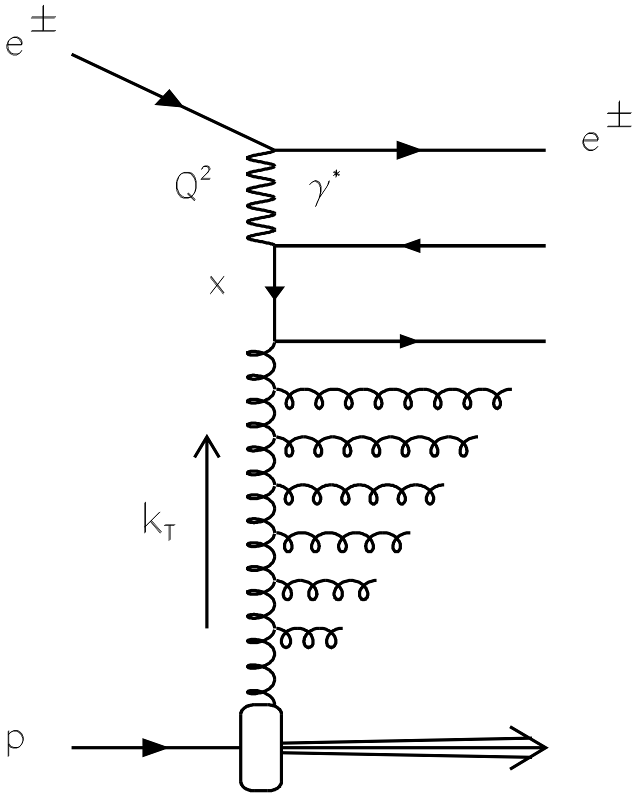
1. Charm production gives large contributions to DIS cross sections $\Rightarrow$ Need to know it well to understand inclusive proton structure data

2. Obtain direct access to gluon density in proton

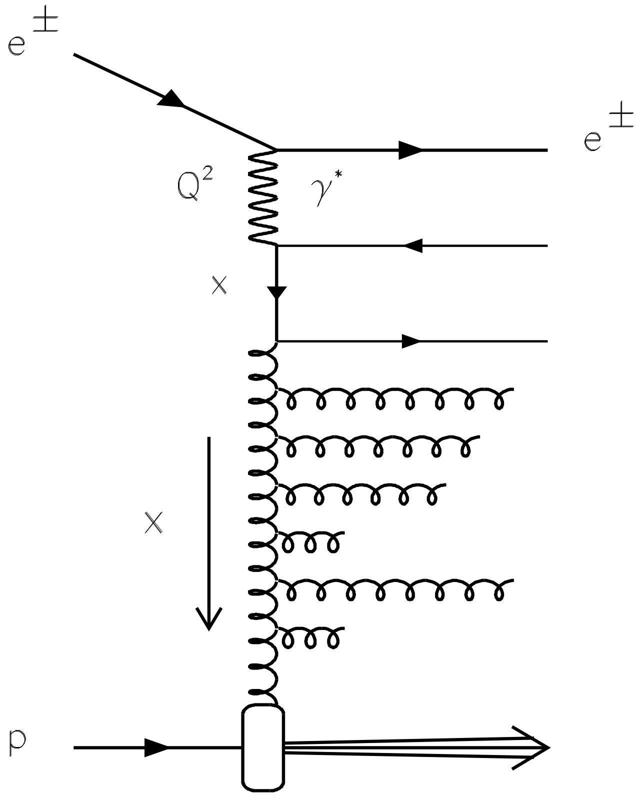
3. pQCD calculation challenges:
   - Significant higher order $O(\alpha_s^2)$ corrections
   - Two hard scales m_c and Q^2 available $\Rightarrow$ Can we treat at large Q^2 charm as massless sea-quarks?

How to treat multi gluon emission?

DGLAP evolution



BFKL evolution

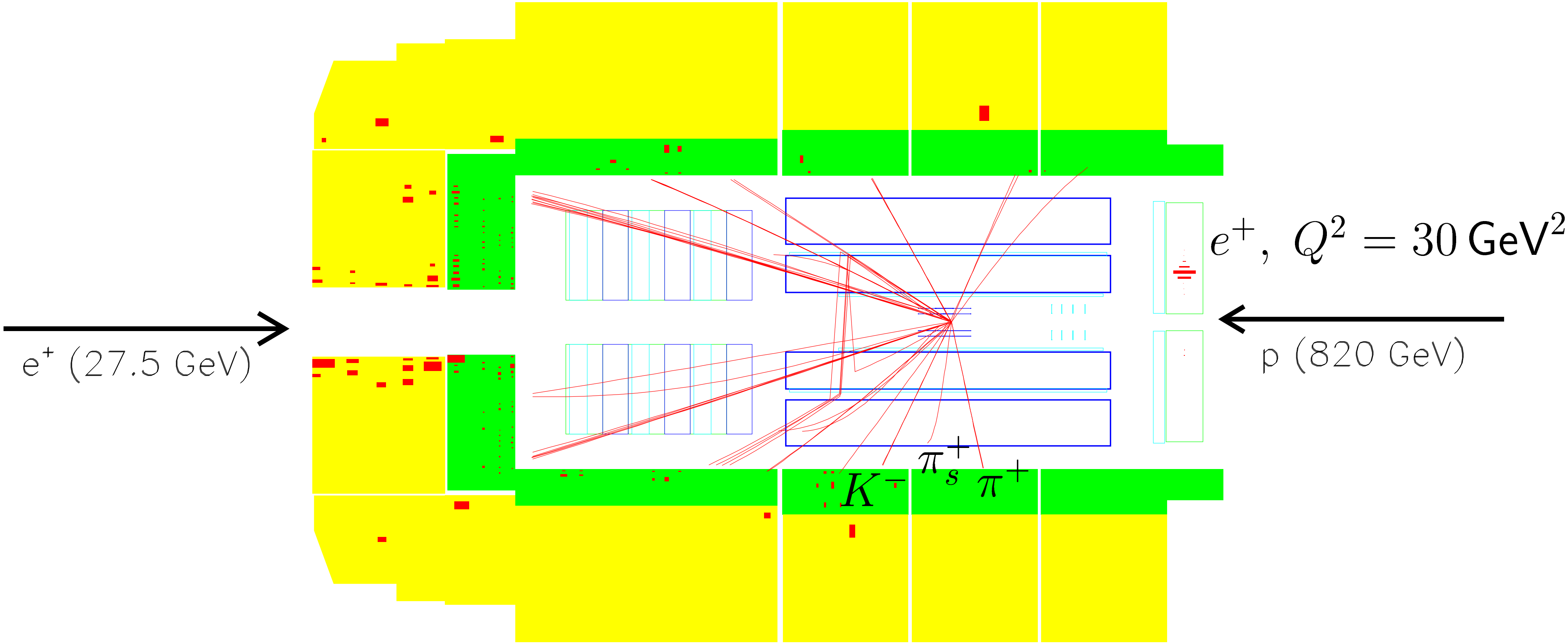


- DGLAP (BFKL) gluon cascade strongly ordered in k_T (x)
- DGLAP evolution is standard in NLO calculations
- CCFM evolution interpolates between DGLAP and BFKL $\rightarrow$ implemented in CASCADE MC

$\Rightarrow$ Can we see effects in our charm data?

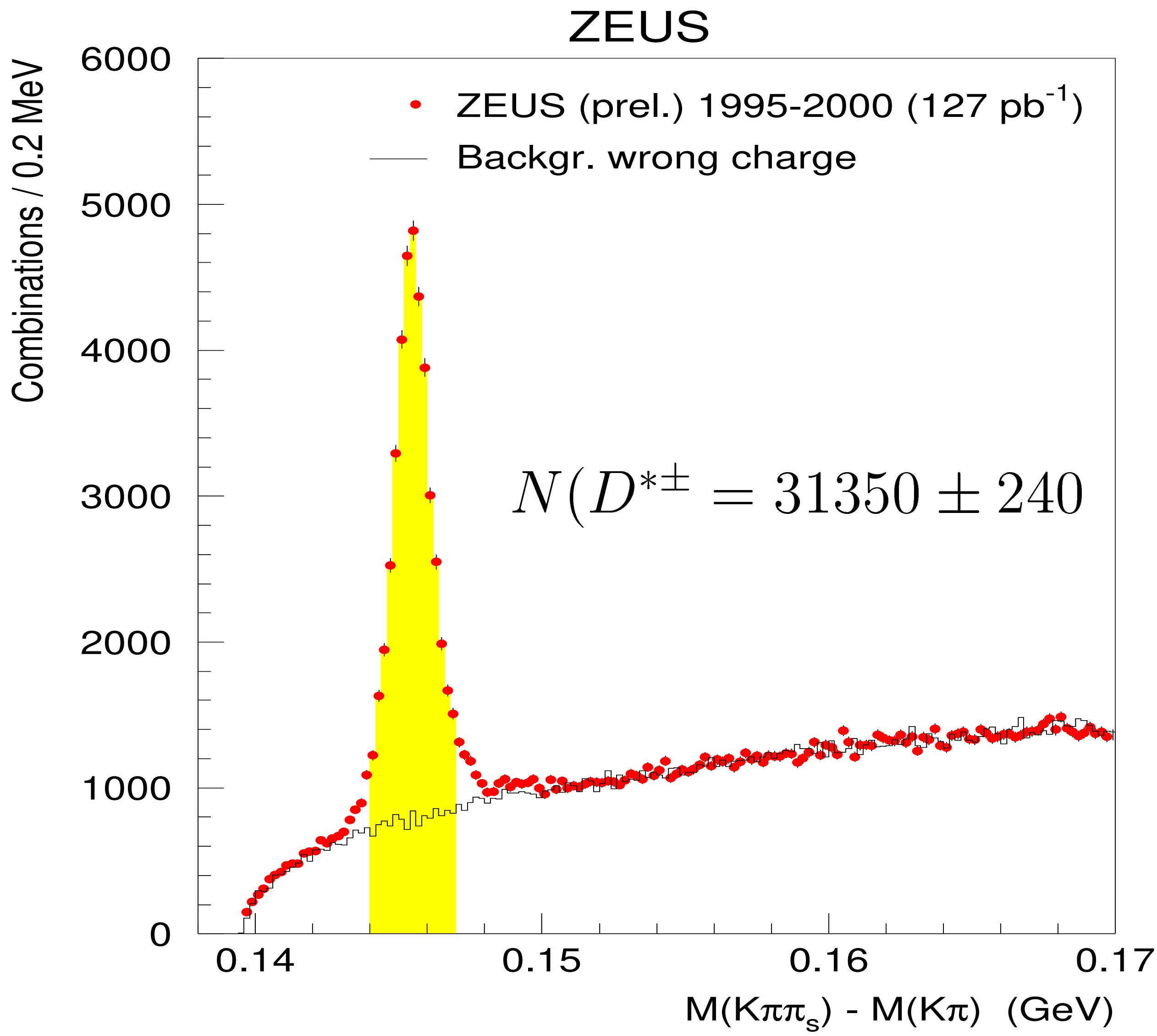
Charm candidate event in the H1 detector

$D^{*+} \to D^0 \pi_s^+,\ D^0 \to K^- \pi^+$ event candidate



Charm tagging

- Main working horse is
  $D^{*+} \to D^0 \pi_s^+,\ D^0 \to K^- \pi^+$



- Other channels:
  - ZEUS: $D^{*+} \to K4\pi$; $c \to eX$
  - H1: Secondary Vertex tagged D-mesons (see Talk by J. Wagner)

Data sets presented today

Collab.	ZEUS	H1	ZEUS
Channel	$D^* \to K2\pi(K4\pi)$	$D^* \to K2\pi$	e
Data	1996-1997	1997	1996-1997
Lumi $\mathcal{L}$	37 pb^{-1}	18 pb^{-1}	34 pb^{-1}
Kinematic cuts	$1 < Q^2 < 600$ GeV^2 $0.02 < y < 0.7$	$1 < Q^2 < 100$ GeV^2 $0.05 < y < 0.7$	$1 < Q^2 < 1000$ GeV^2 $0.03 < y < 0.7$
Selection cuts	$p_T(D^*) > 1.5(2.5)$ GeV $\lvert\eta(D^*)\rvert < 1.5$	$p_T(D^*) > 1.5$ GeV $\lvert\eta(D^*)\rvert < 1.5$	$1.2 < p_e < 5$ GeV $\lvert\eta_e\rvert < 1.1$

QCD calculations to compare with

- NLO Fixed Order α_s^2 calculations; "Massive" 3 Flavour Scheme

$$\sigma = g(x) \otimes \hat{\sigma}_{BGF} \otimes D_{non-pert}(z)$$ with $D(z)$ Peterson Fragm. Funct.

Used for D^* analyses:

Collab.	ZEUS	H1
Programs:	"HVQDIS" (Harris & Smith)	
PDFs	ZEUS F2 NLO Fit	GRV98-HO
Charm mass	$1.3 < m_c < 1.5$ GeV	
Scales	$\mu_r = \mu_f = \sqrt{Q^2 + 4m_c^2}$	
Fragmentation $\parallel$	$\epsilon_c = 0.035$	$0.035 < \epsilon_c < 0.1$
Fragmentation $\perp$	-	$p_t \cdot exp(-\alpha p_t)$
$f(c \to D^*)$	0.222 (OPAL)	0.233 (ALEPH)

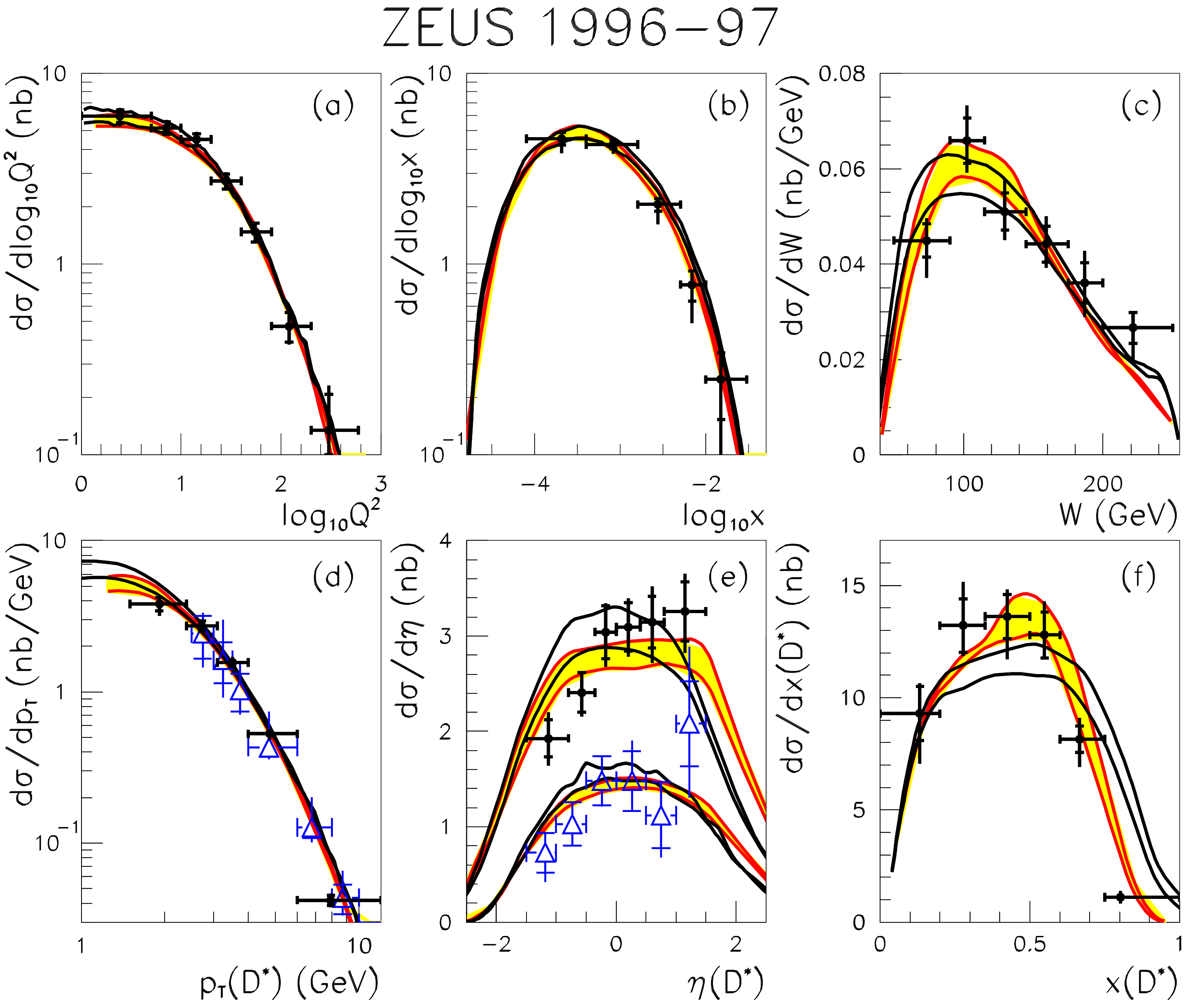
- CASCADE LO MC: CCFM evolution, "unintegrated" k_T-dependent gluon density

D^* differential cross sections (ZEUS)

Black data points $K2\pi$, blue data points $(K4\pi)$ channel

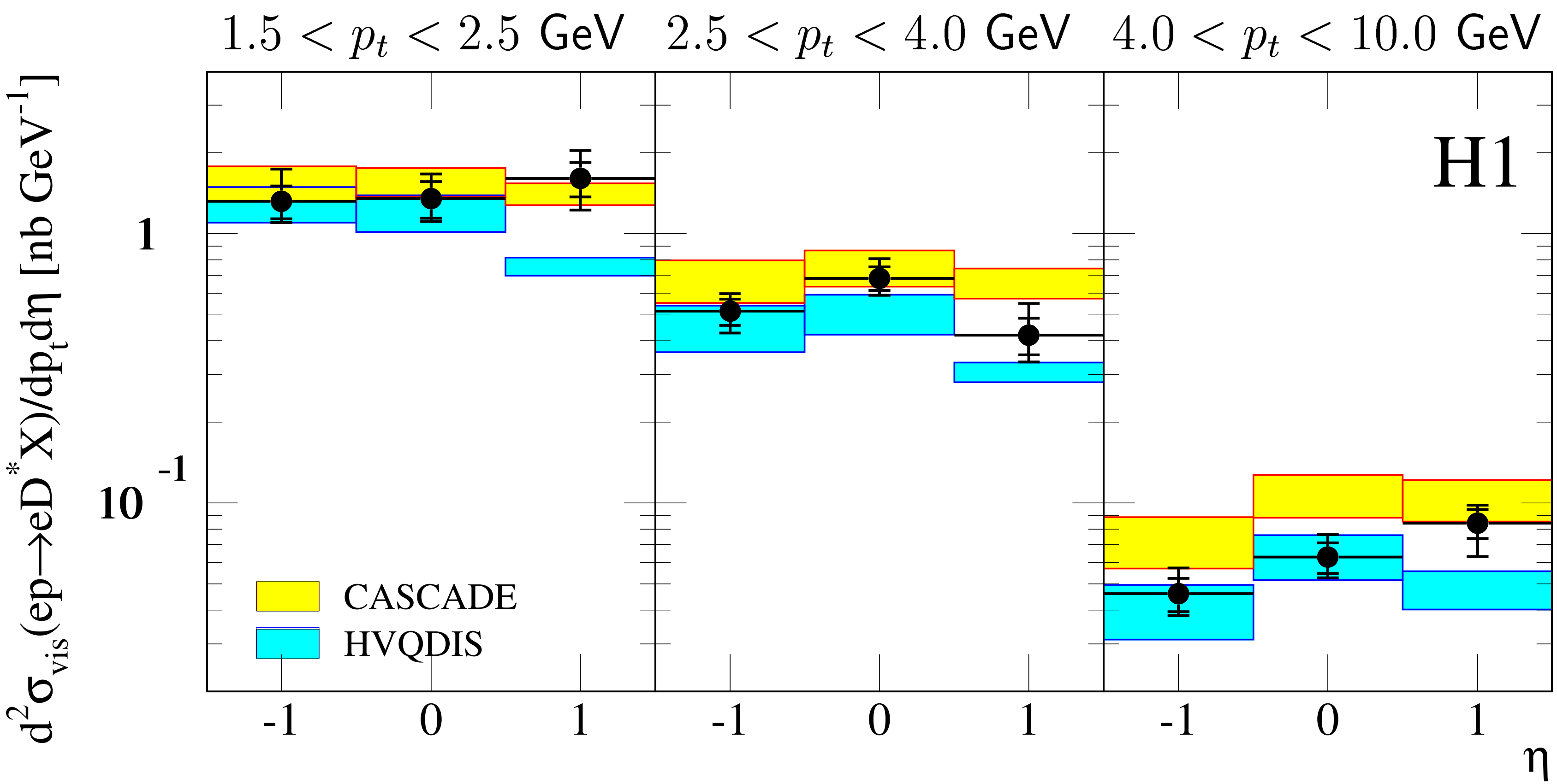
Open bands HVQDIS with Peterson fragmentation

Coloured bands HVQDIS reweighted with Jetset fragment.



- Reasonable description by NLO
- $\eta(D^*)$ distribution sensitive to fragmentation

Double diff. D^* xsec, H1



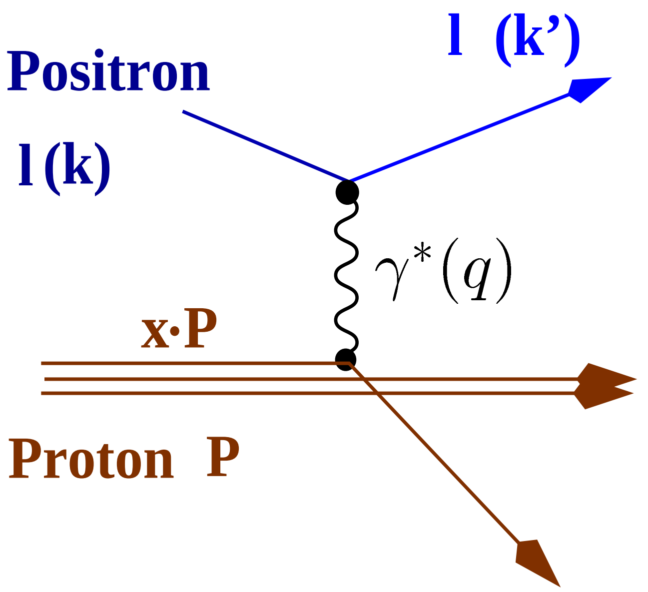
$\Longrightarrow$ HQVDIS undershoots significantly forward D^* data

$\Longrightarrow$ CASCADE describes $\eta(D^*)$ shapes better, but overshoots data at large p_t

Charm contribution to DIS $\rightarrow F_2^{c\bar{c}}$

$$\frac{d^2\sigma^{ep}}{dQ^2dx} = \frac{2\pi\alpha^2}{Q^4x} \cdot (1 + (1-y)^2) \cdot F_2(x, Q^2)$$

QPM model:



$$F_2 = \sum_i e_i^2 (q_i(x) + \bar{q}_i(x))$$

- Production model independent generic definition of $F_2^{c\bar{c}}$:

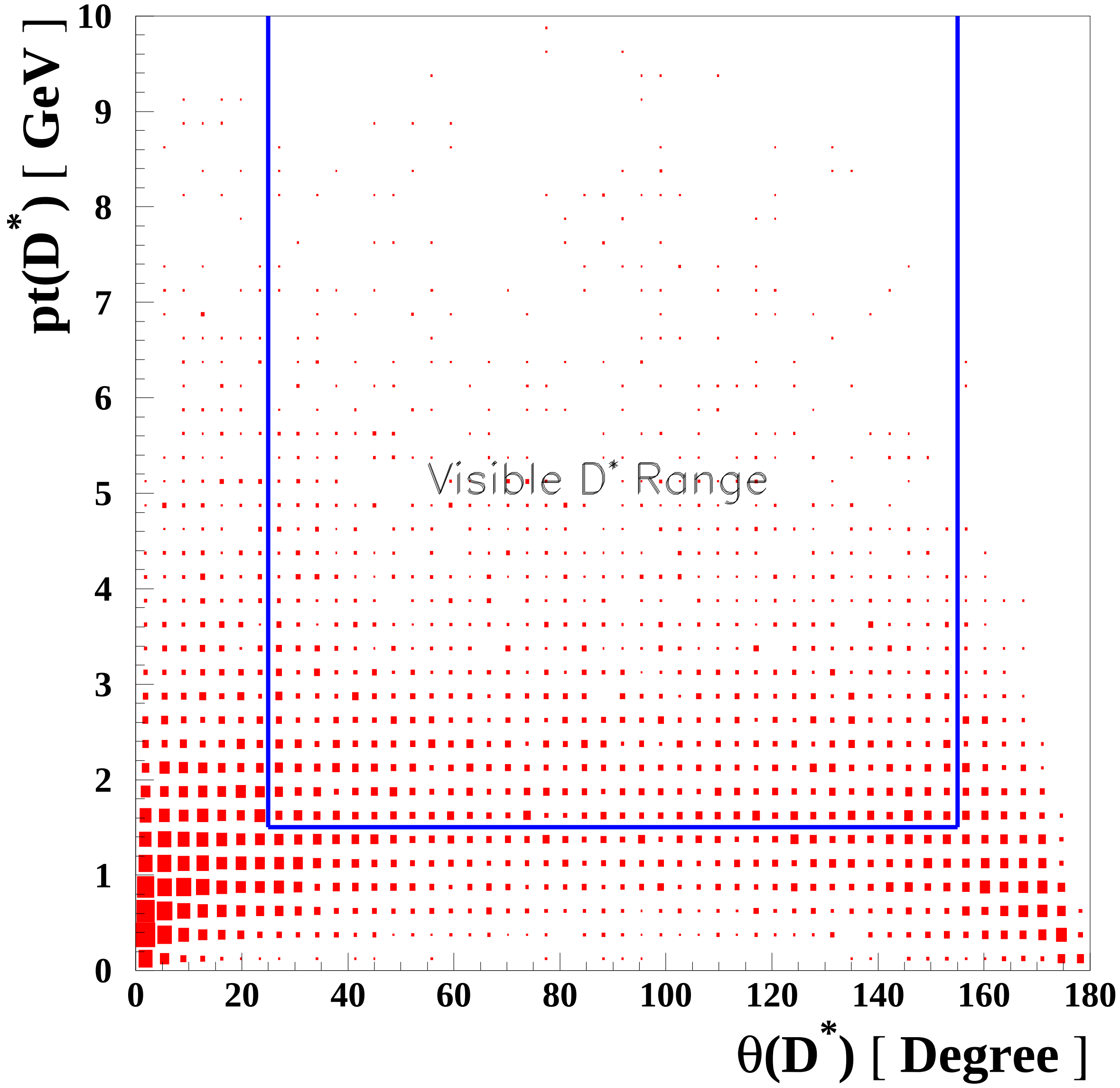
$$\frac{d^2\sigma^{ep\rightarrow c\bar{c}x}}{dQ^2dx} = \frac{2\pi\alpha^2}{Q^4x} \cdot (1 + (1-y)^2) \cdot F_2^{c\bar{c}}(x, Q^2)$$

- To determine $F_2^{c\bar{c}}$ extrapolate D^* measurements to full $P_T(D^*)$,$\eta(D^*)$ phase space

Extrapolation

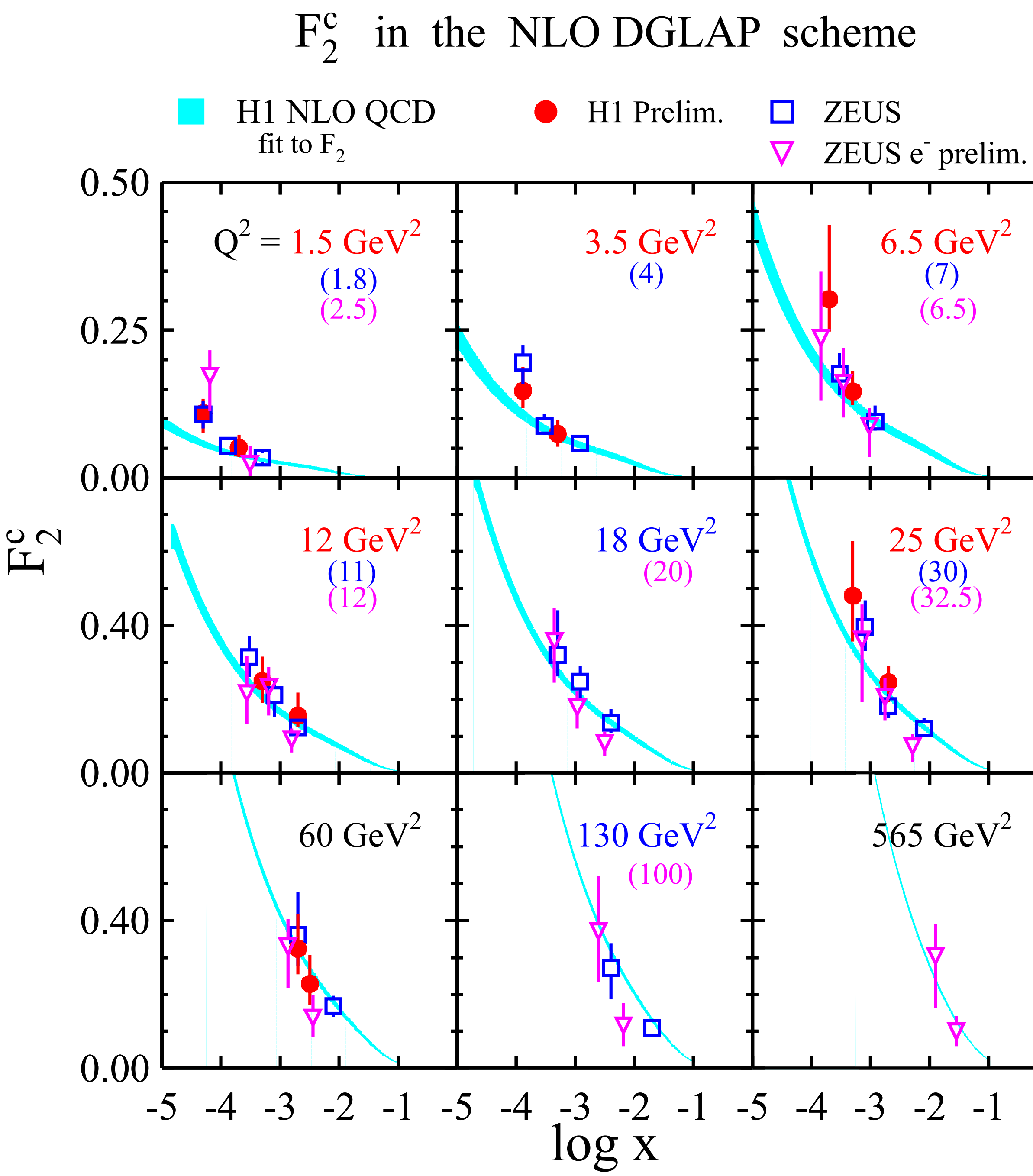
Test extrapolation with Django LO MC with cuts $Q^2 > 1$ GeV^2, $0.02 < y < 0.7$

$\Rightarrow$ Obtain $p_t(D^*)$ vs. $\theta(D^*)$ generator spectra:



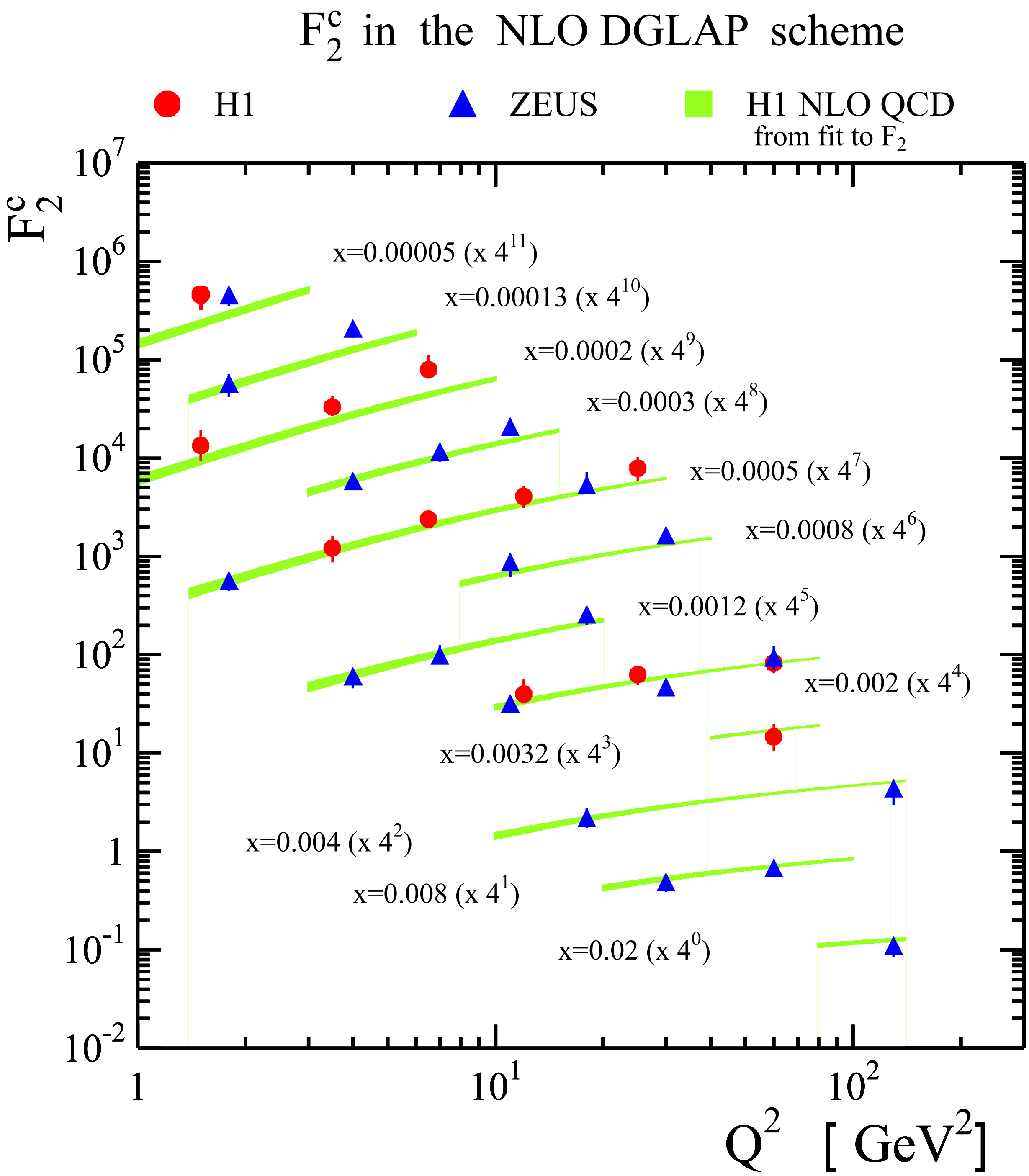
- Large Extrapolation factors!
- Extrapolation factors decrease with higher Q^2

F_2^c results



- NLO calculation with gluon from fit to F_2 describes data reasonably
- Strong rise towards low x and high Q^2
  $\Rightarrow$ driven by gluon density in proton

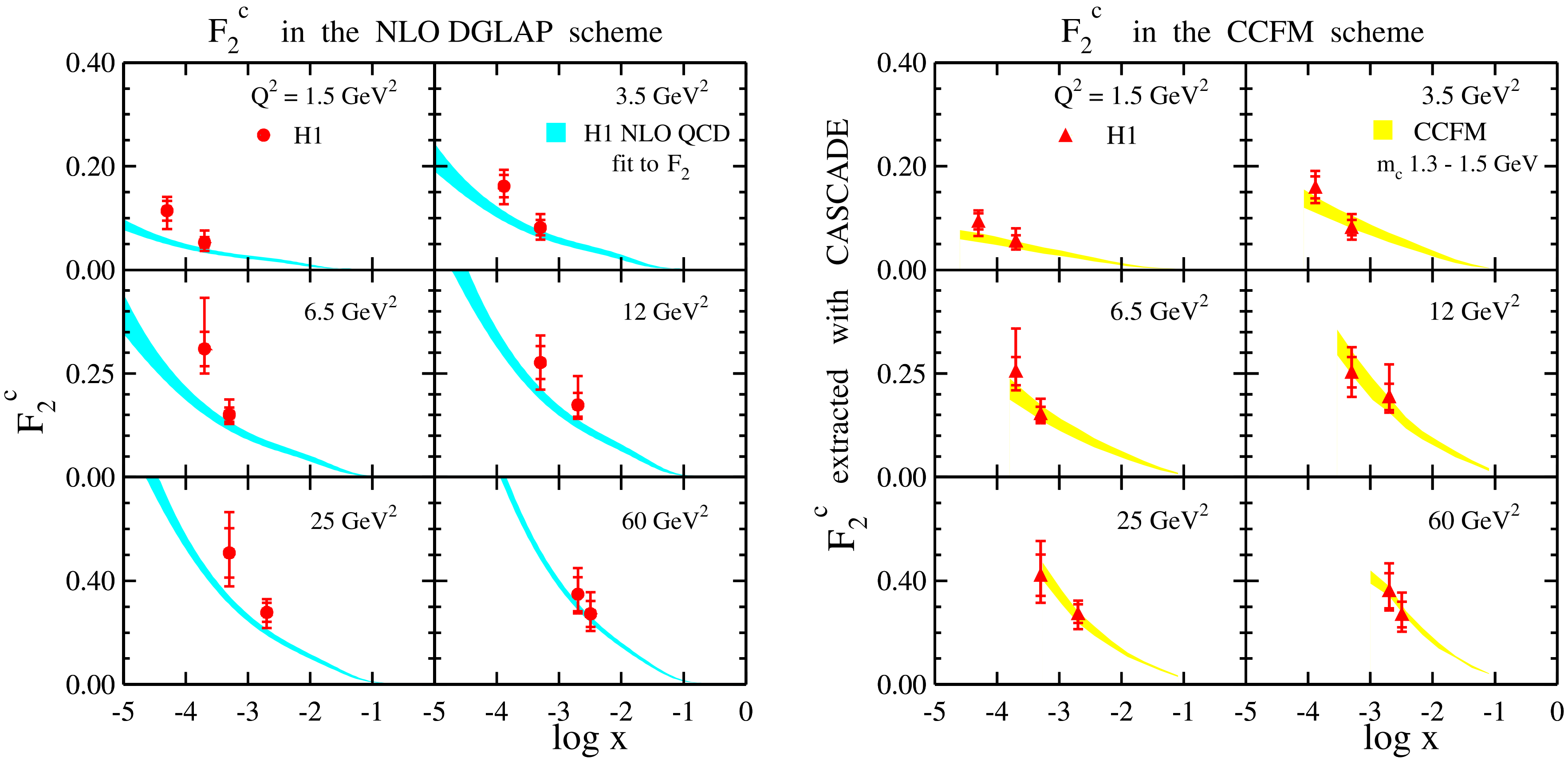
Scaling violations in F_2^c



⇒ Steeper Q^2 dependence than for the inclusive structure function

⇒ $\partial F_2^c / \partial Q^2$ contributes about 50 % to the scaling violations of F_2

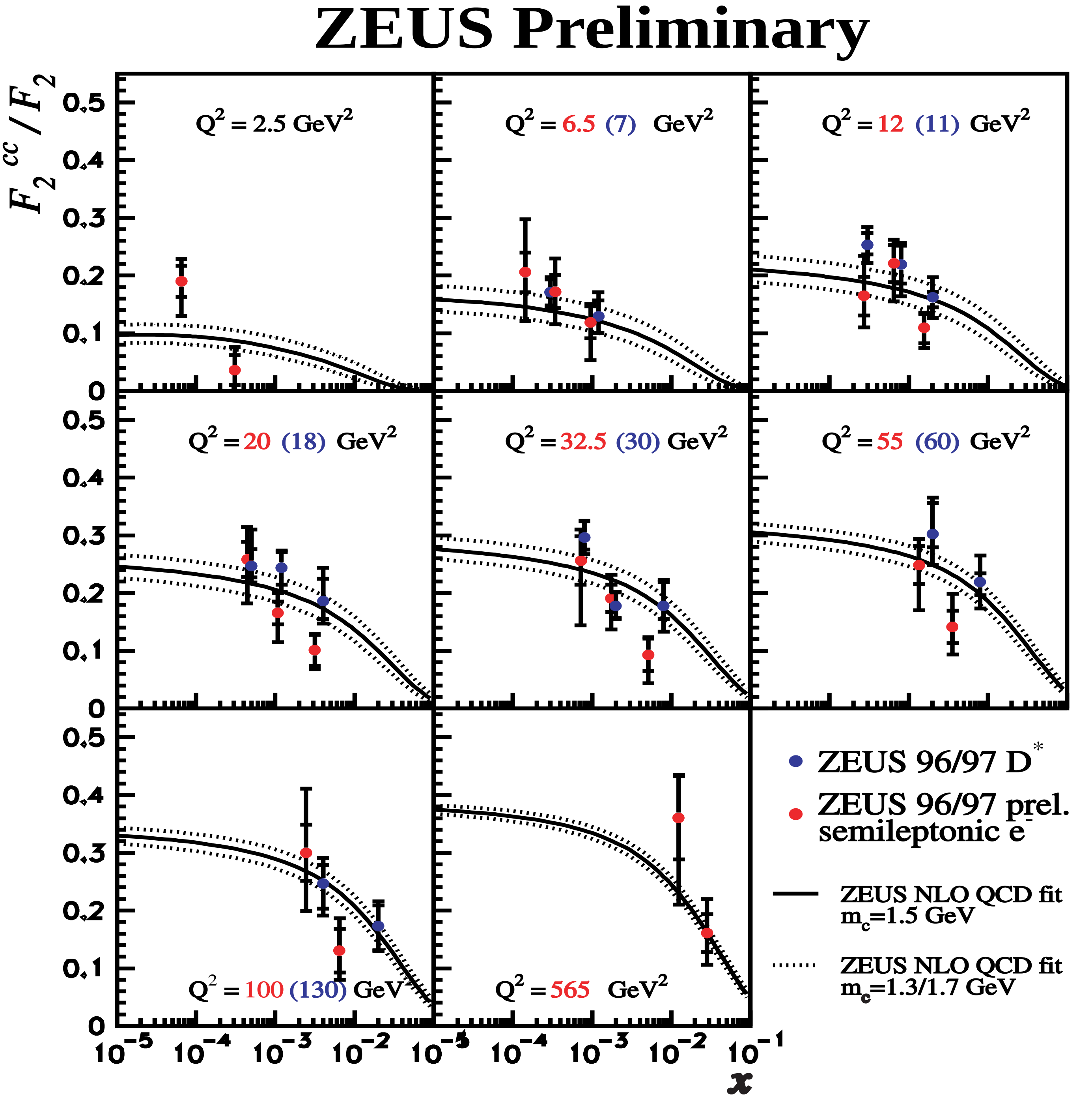
F_2^c extracted in two different schemes



- Smaller extrapol. factors using CCFM $\Rightarrow$ smaller extracted F_2^c
  $\Rightarrow$ Need larger detector acceptances or smaller QCD model uncertainties to pin down F_2^c with less systematics!!!

Ratio F_2^c/F_2

$\equiv$ Fraction of events with charm production

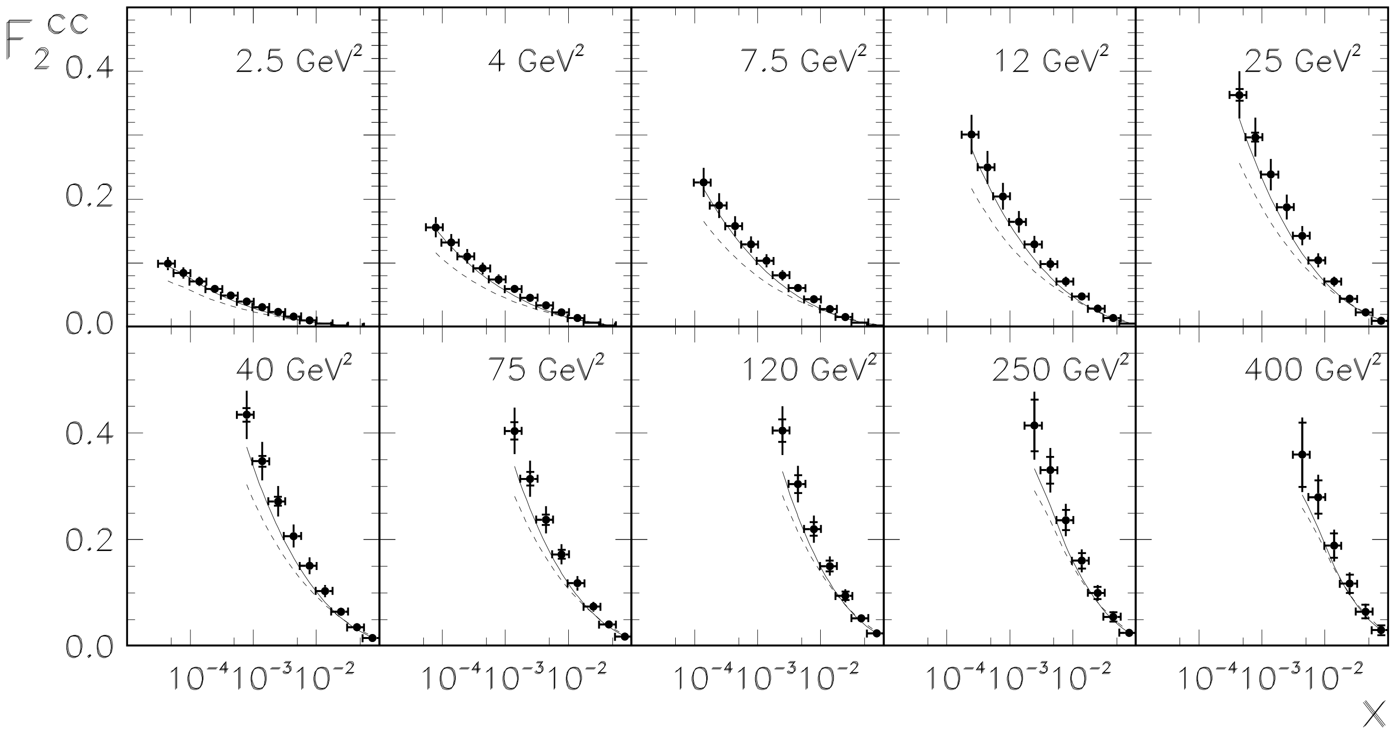


$\Rightarrow$ Approaches at high Q^2 ,low x "democratic limit" of 4/11 (d=1,s=1,b=1,u=4,c=4)

Outlook

- HERA I: F_2^c results with full statistics ($\sim$ 100 pb^{-1}) yet to come
- HERA II: Upgrades!
  - Lumi $\rightarrow$ record 500 pb^{-1}
  - Detectors: Forward tracking, more Si trackers, better track triggers $\Rightarrow$larger acceptances!

F_2^c in 2006 with 500 pb^{-1}:



$\Rightarrow$ Measure charm contribution precisely up to $Q^2 \approx 1000$ GeV^2

Conclusions:

- Charm contributes "heavily" to DIS
  $\Rightarrow$ is a key to understanding of proton structure, in particular of the gluon
- NLO QCD does *overall* a *fairly* good job in describing the observed charm cross sections
- With HERA II charm data we will (hopefully!)
  a) pin down proton gluon density precisely
  b) answer some of the global key questions, e.g.
     can we find signs of BFKL?
  c) take a look into so far unexplored regions (e.g. higher Q^2)
     can we find deviations from the BGF picture?