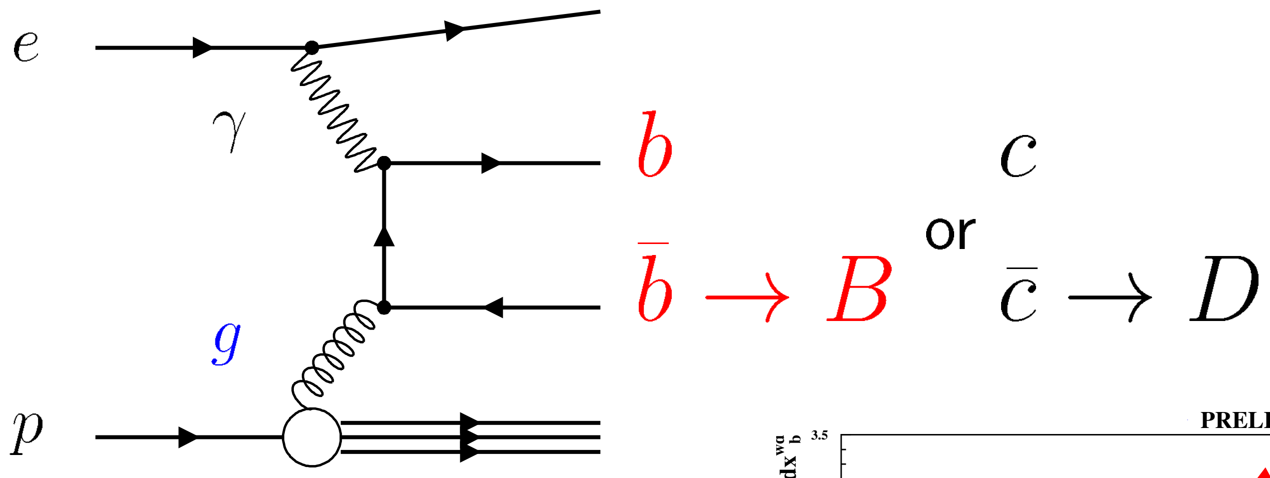
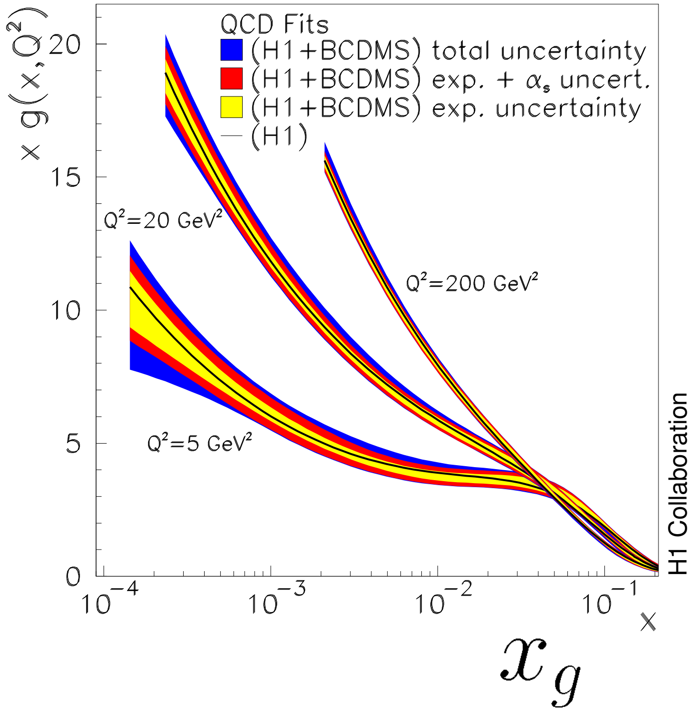
Heavy Quark Production in Deep-Inelastic Scattering

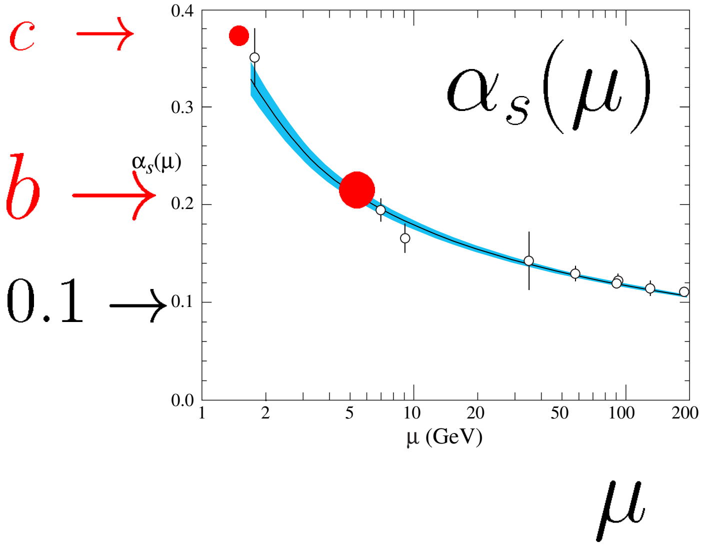
Felix Sefkow
Universität Zürich
on behalf of the H1 and ZEUS Collaborations

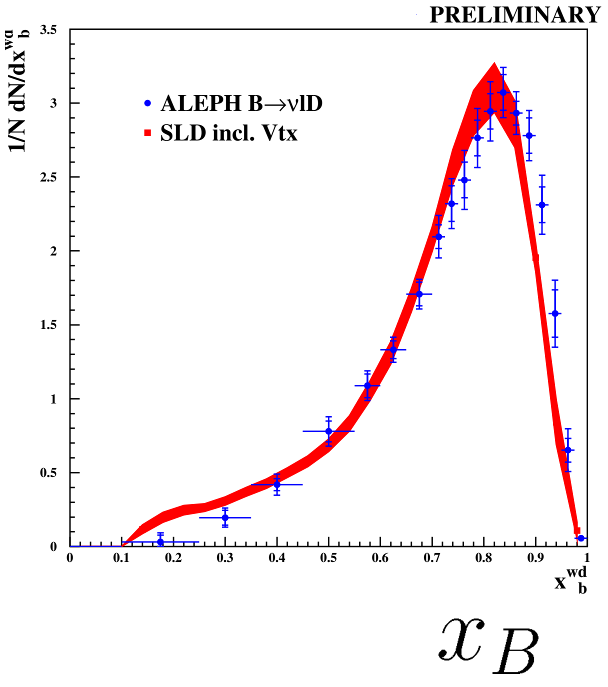
New HERA results on Charm and Beauty

HERA's Beauty Case









- QCD testing ground *par excellence*
- Understanding mandatory to interprete proton structure data

QCD Tools

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

  $\sigma = g(x) \otimes \hat{\sigma}_{BGF} \otimes D_{non-pert}(z)$ $(\otimes$ semilept. decay $)$

  $D(z)$ Peterson Fragmentation Function

  "HVQDIS" (Harris & Smith); "FMNR" (Frixione *et al*) for γp

  K-factors NLO / LO $\sim$ 1.4 – for charm and beauty

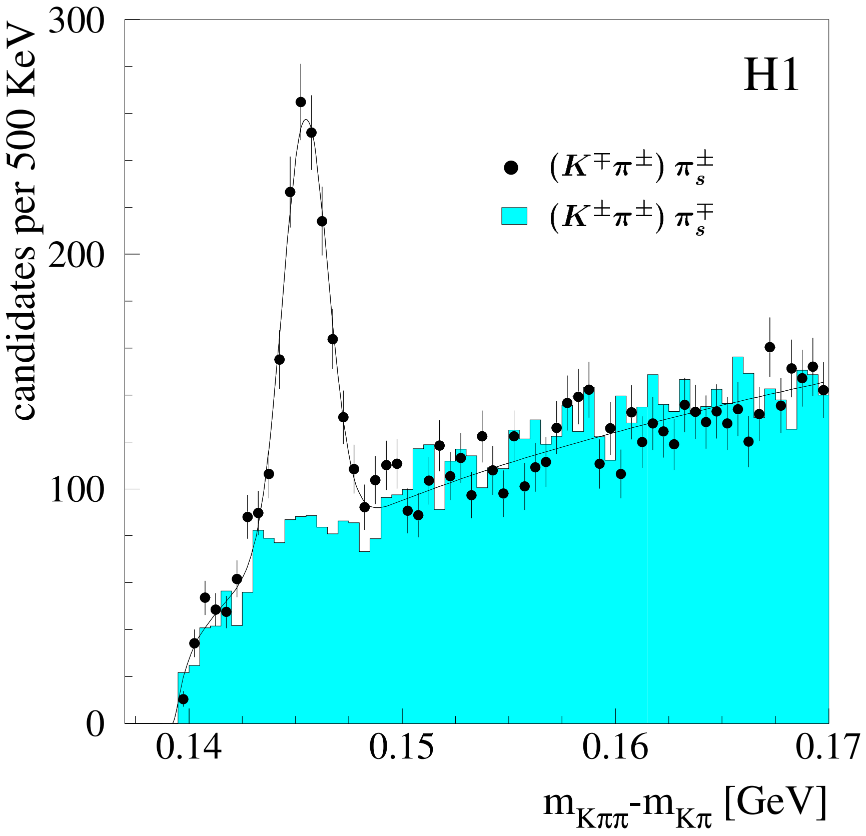
- LO MC programs:

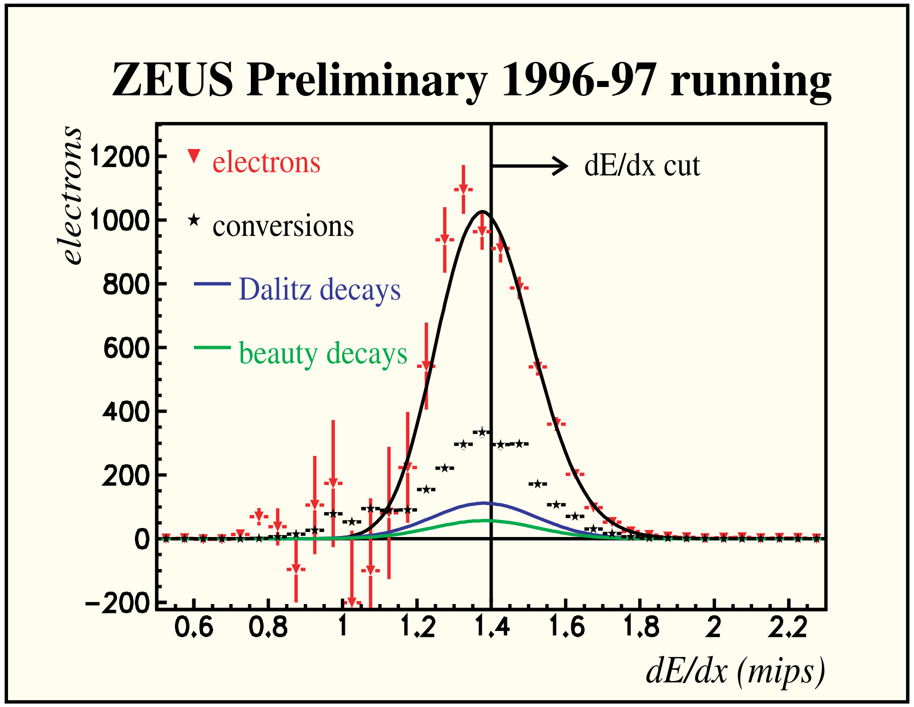
  AROMA: Altarelli-Parisi evolution, leading log parton showers

  CASCADE: CCFM evolution, "unintegrated" k_t-dependent PDFs

Charm and Beauty Signals

- $D^* \to D^0\pi^+ \to K^-\pi^+\pi^+$
- semileptonic decays:
  - ▷ muons (H1)
  - ▷ electrons (ZEUS)





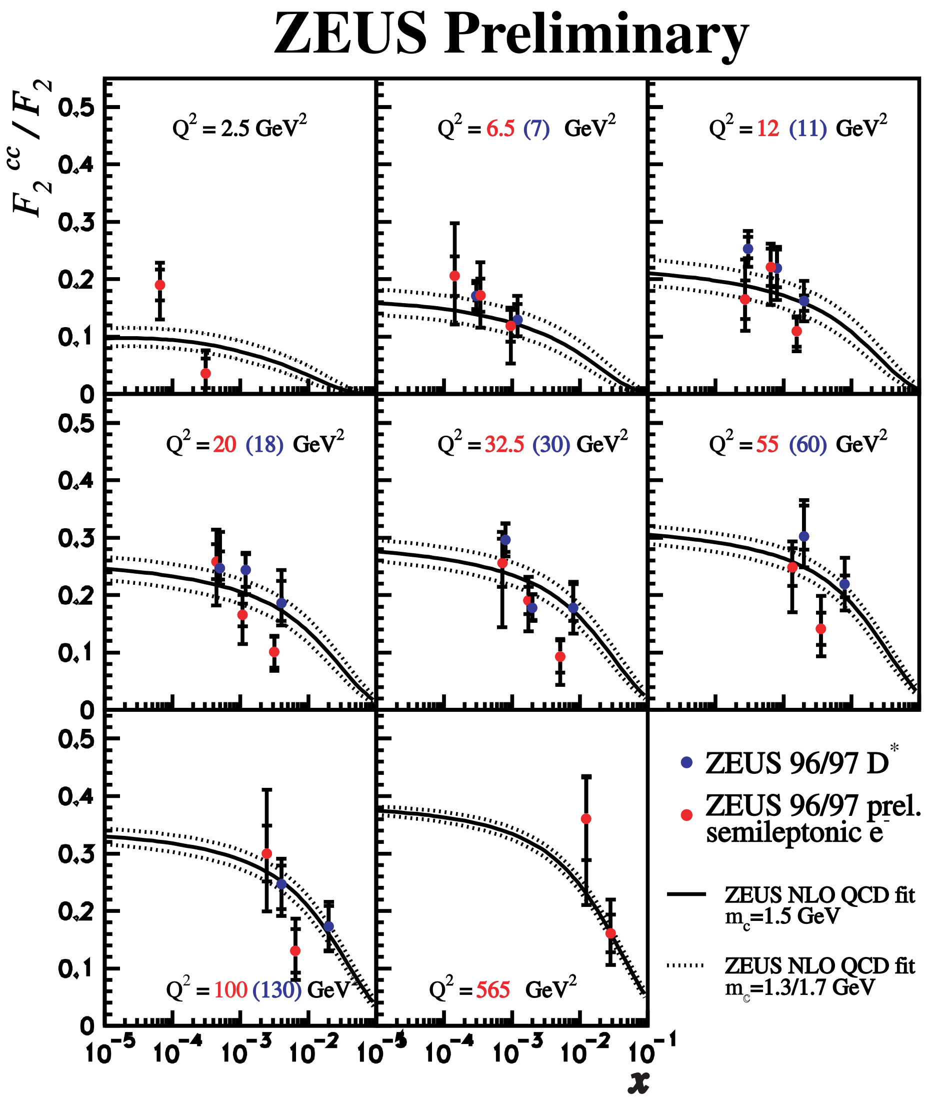
Charm Contribution to DIS: Ratio F_2^c/F_2

- Charm contribution F_2^c to proton structure function:

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

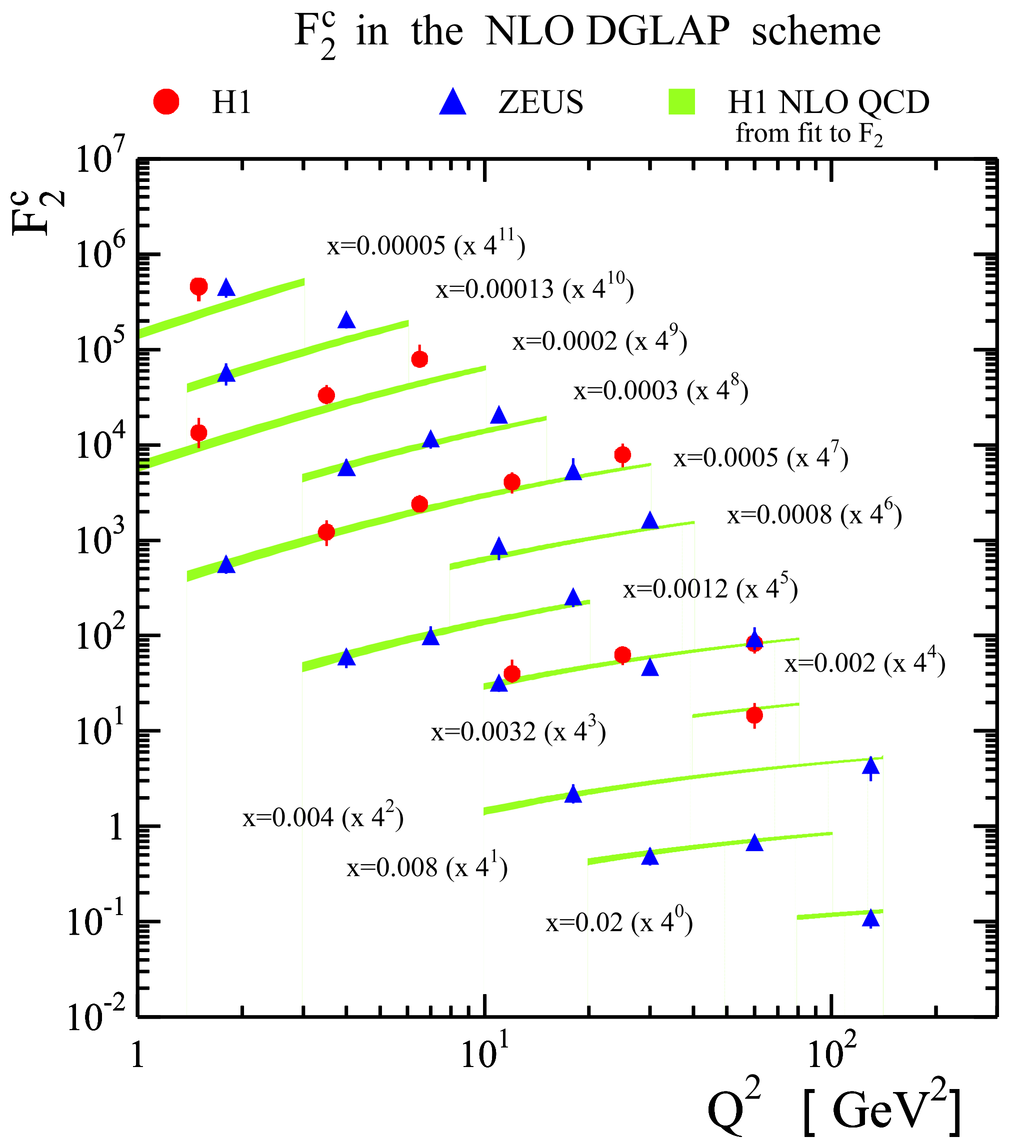
DIS scaling variables: x_{Bjorken}, Q^2

$\rightarrow$ F_2^c/F_2 is large at low x (where gluons dominate)



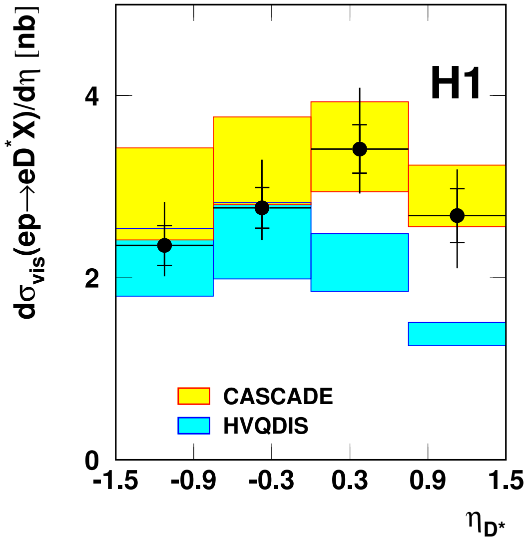
- D^* and semilept. data agree

Scaling Violations in F_2^c



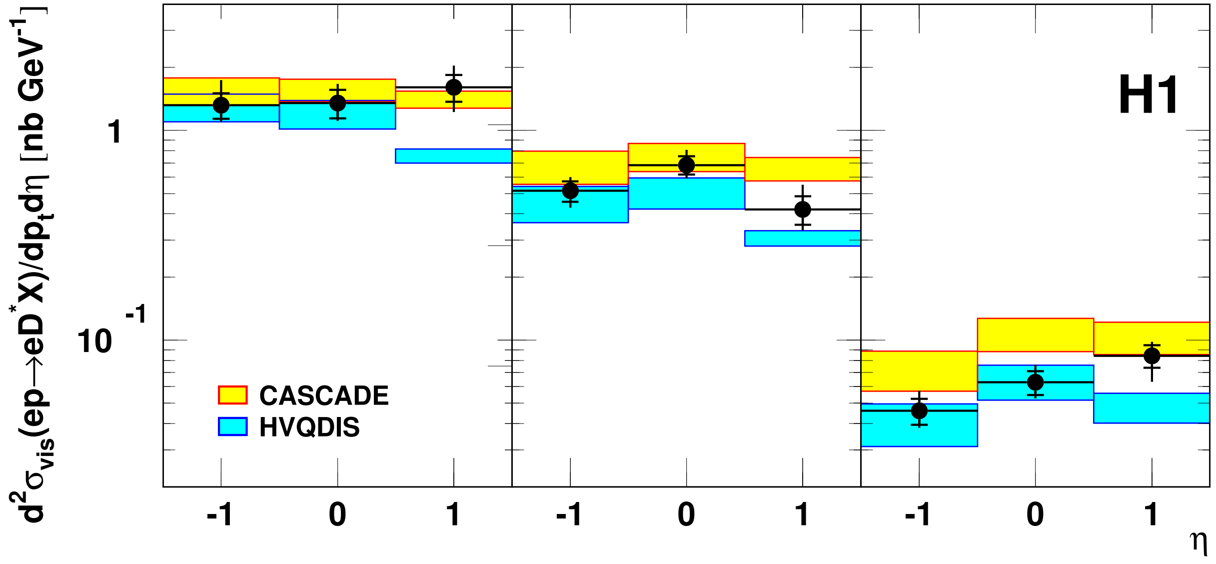
- Q^2 dependence steeper than for the inclusive structure function
- $\partial F_2^c / \partial Q^2$ contributes about 50 % to the scaling violations of F_2
- data tend to be higher and steeper than theory at low x
- H1 and ZEUS agree

Double Differential D^* Cross Sections



- Discrepancy between data and NLO QCD at larger rapidities
  $\rightarrow$ mostly at low p_T
  (but not only at low Q^2)
- CASCADE MC desribes this region well.

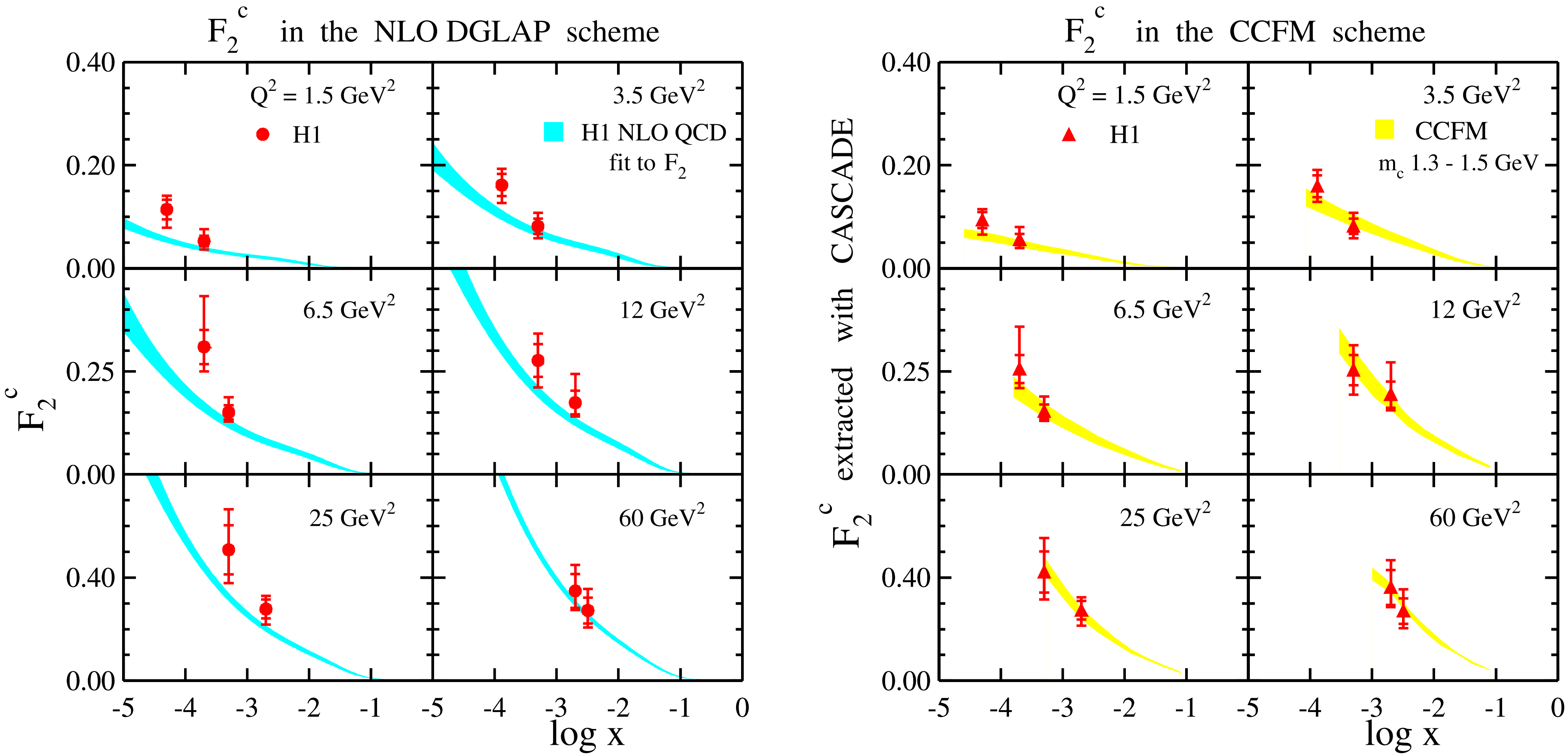
$1.5 < p_T < 2.5$ $\quad$ $2.5 < p_T < 4$ $\quad$ $4 < p_T < 10$ GeV



$$d^2\sigma / d\eta\, dp_T$$

error bands: m_{charm} and fragm.
PDFs: CASCADE: fit to F_2
HVQDIS: GRV'98

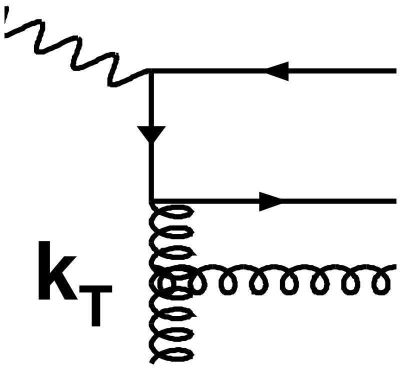
F_2^c in two Schemes



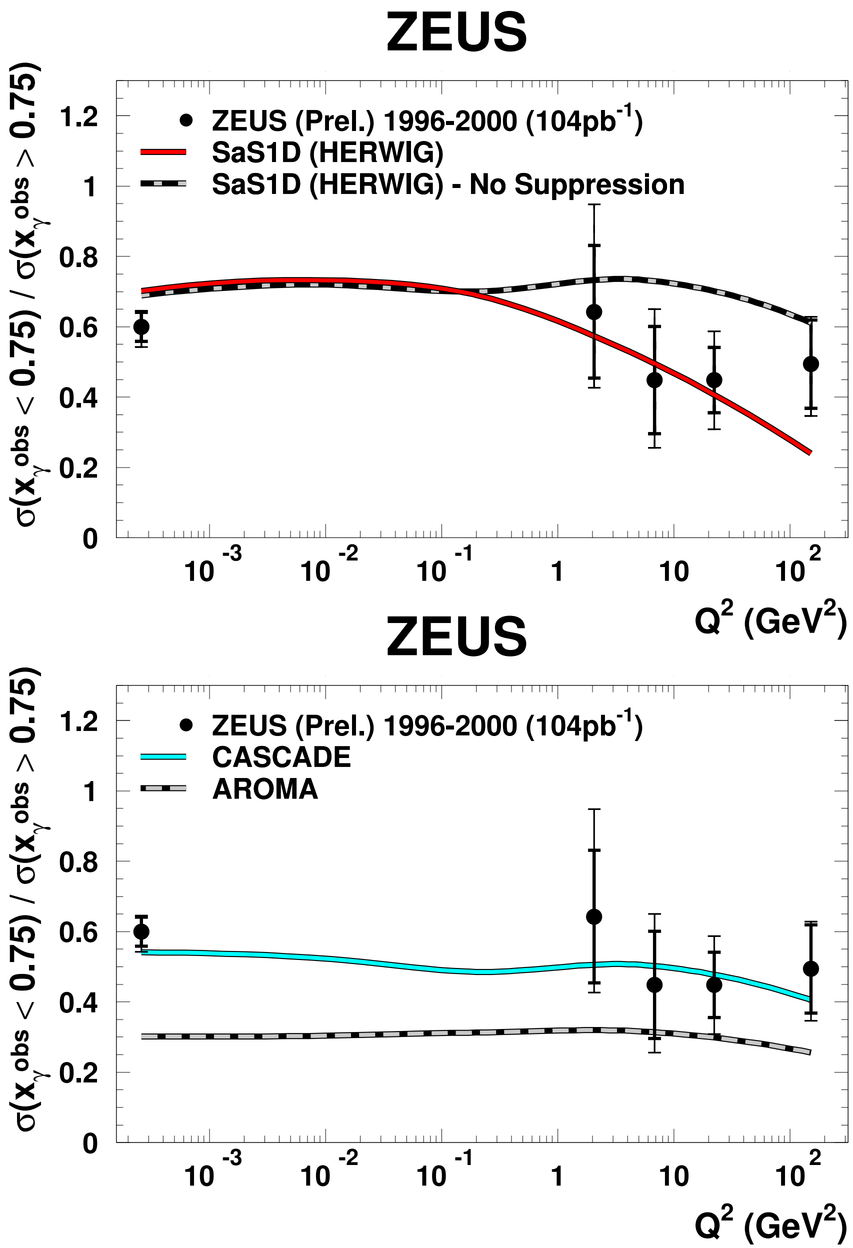
- F_2^c is model-dependent (extrapolations)
- CCFM somewhat better at low x

“Resolved” / ”Direct” Photon *vs.* Virtuality

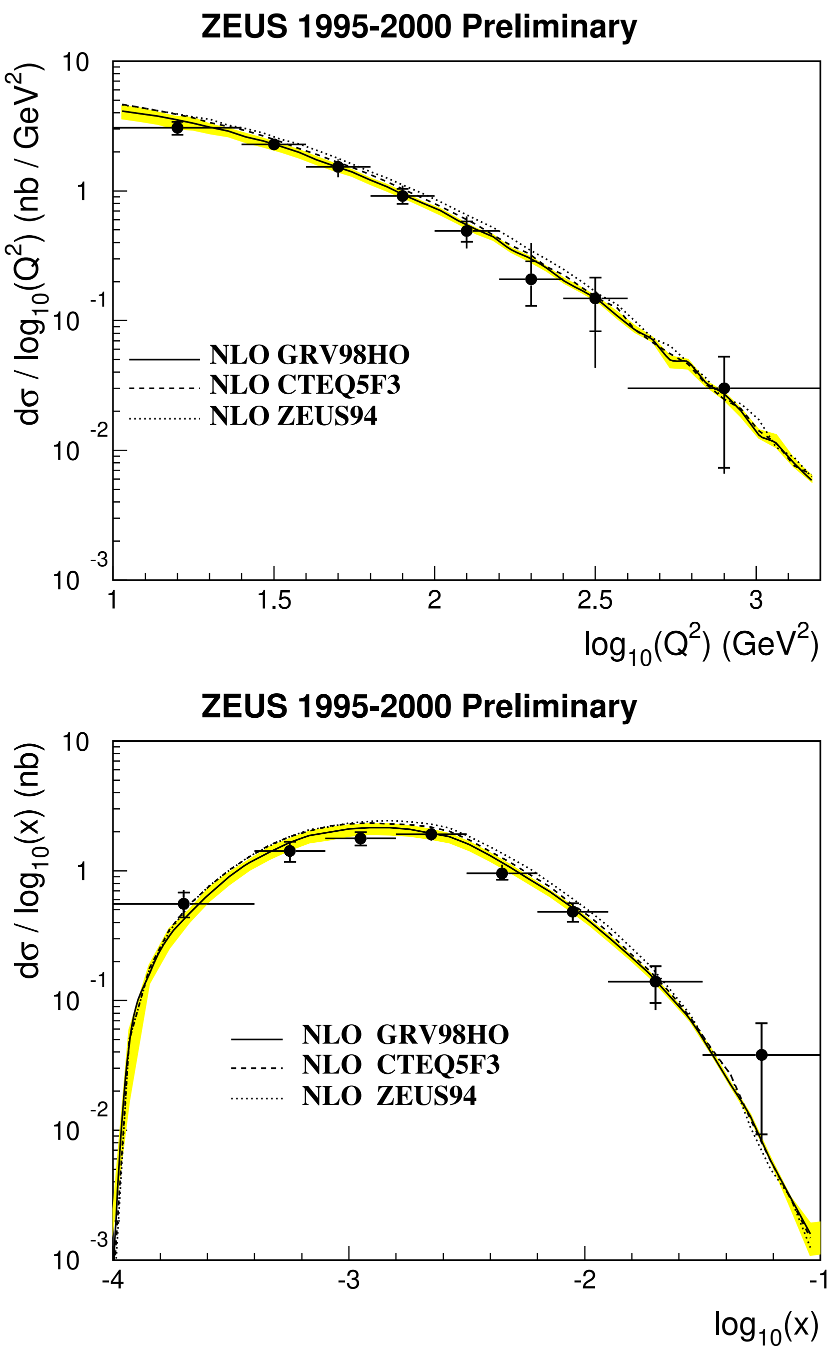
- In dijet events, reconstruct $x_\gamma^{OBS} = (E - p_z)_{2\ jets}/(E - p_z)_{all}$
- sensitive to *any* non-collinear radiation
- “Resolved” if $x_\gamma^{OBS} < 0.75$



- anomalous part effectively included in CASCADE MC

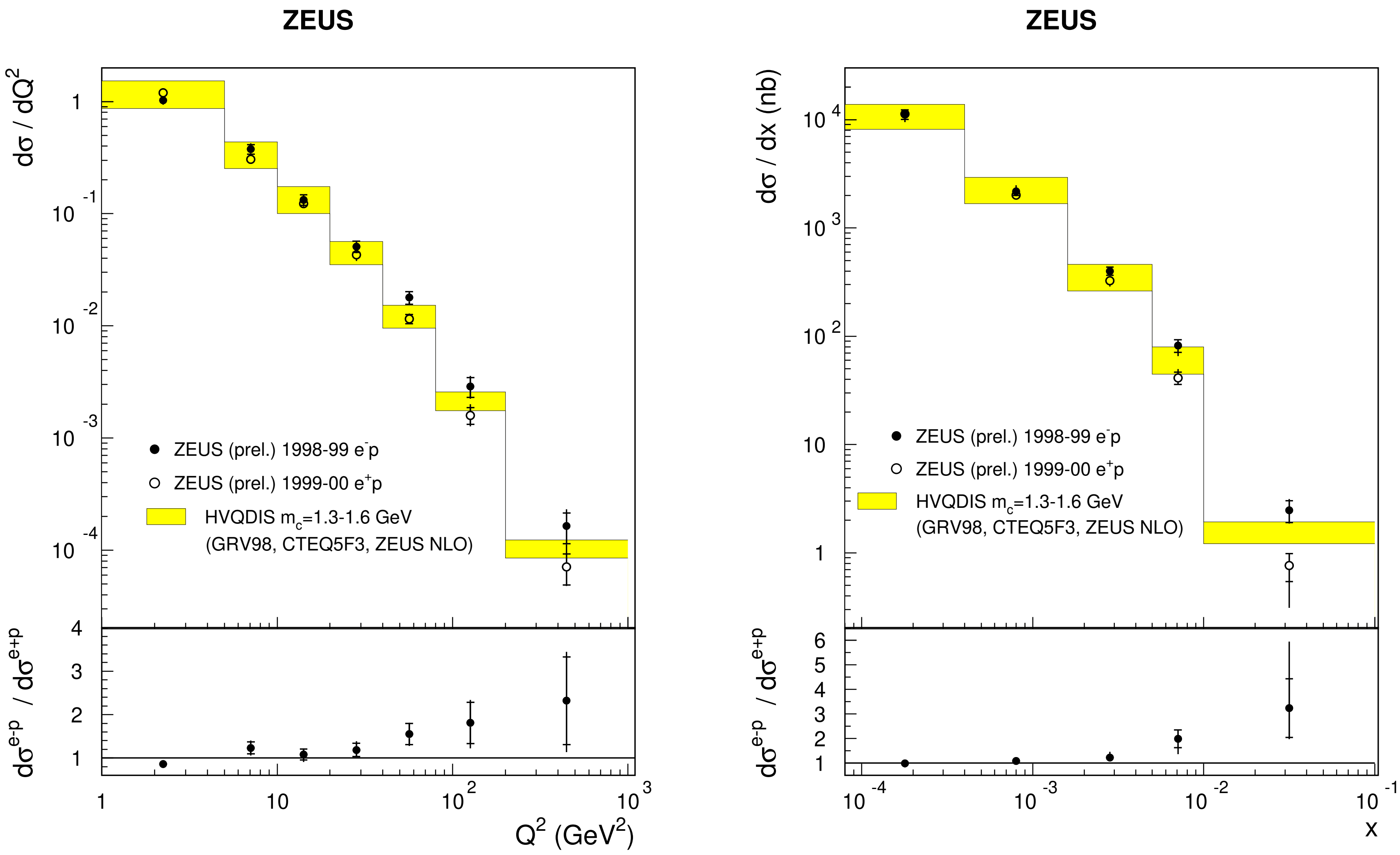


Charm Cross Sections at High x, Q^2



- For $Q^2 \gg m_c^2$ charm should be treated as parton
- 3 Flavour scheme provides good description up to $Q^2 \simeq 1000$ GeV^2 and $x_{Bj} \simeq 0.1$
- Sensitivity to discriminate between different Variable Flavour schemes only at even higher x and Q^2

Compare e^-p *vs.* e^+p Data



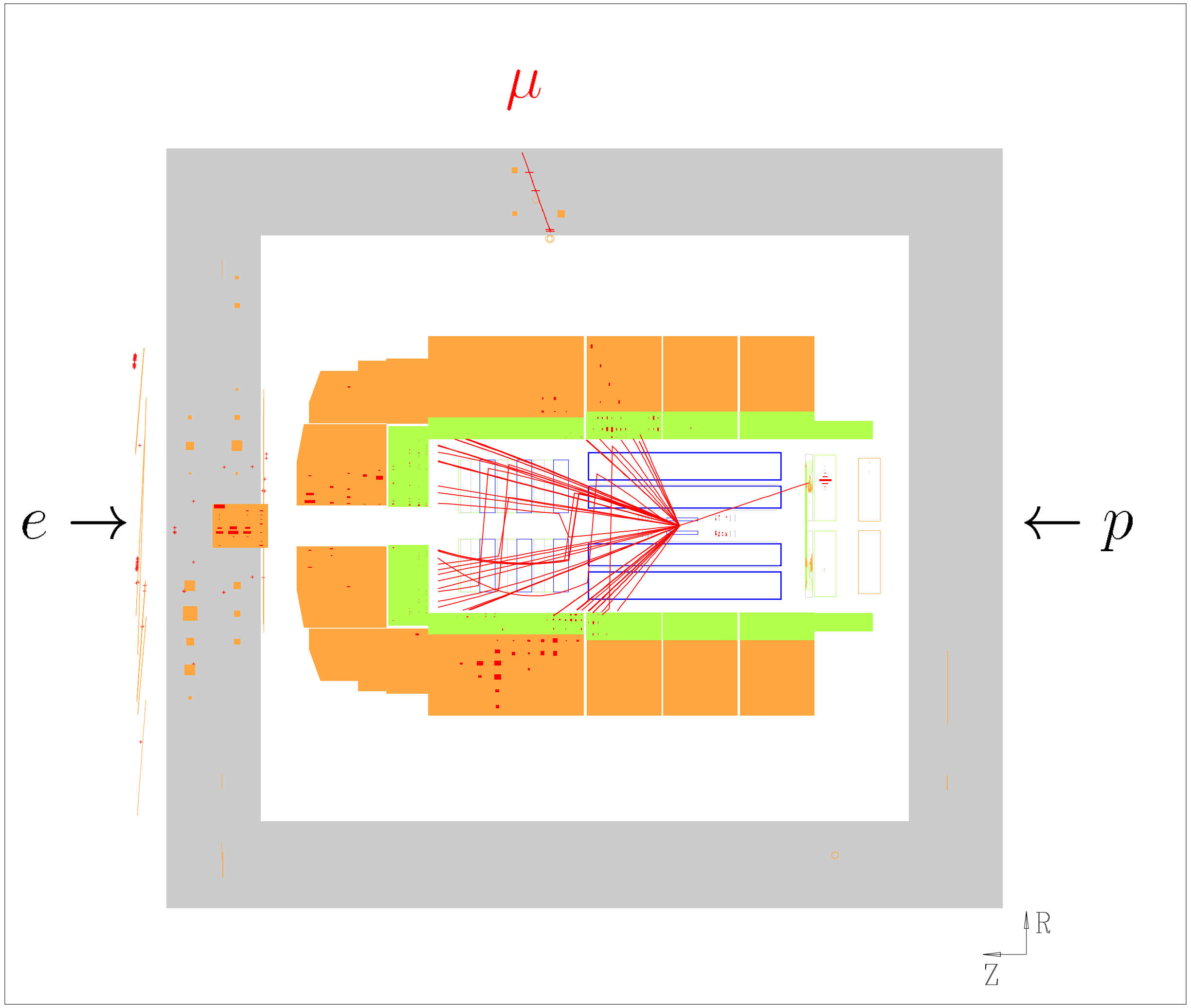
- e^-p and e^+p data only hardly consistent ($Q^2 > 20$ GeV^2: 3σ)
- but both are compatible with theory

Charm Summary:

- The Boson Gluon Fusion Concept in NLO QCD works well in DIS, up to high Q^2.

- HERA data reach the precision to identify regions where refinements are needed.

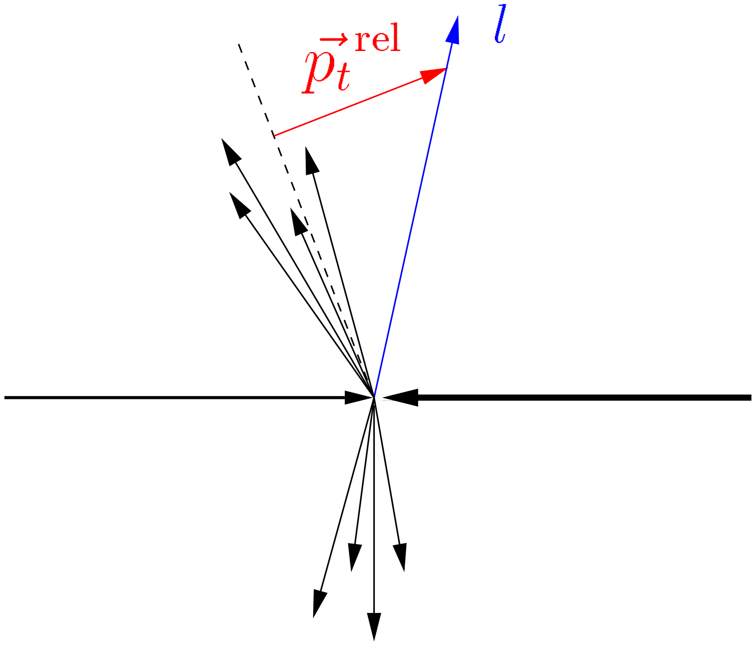
Beauty Production at HERA



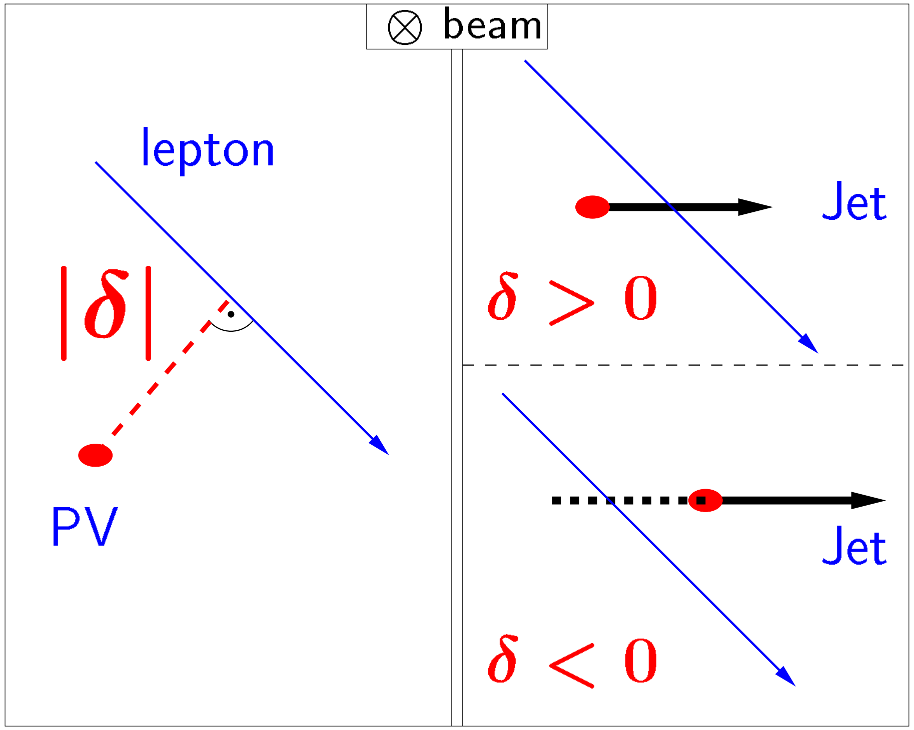
- Low rate:
  expect $\sigma_b/\sigma_c \sim 10^{-2}$
- Signature:
  semileptonic decays
  in dijet events

Signs of Beauty: Mass and Lifetime

- lepton p_t w.r.t. jet

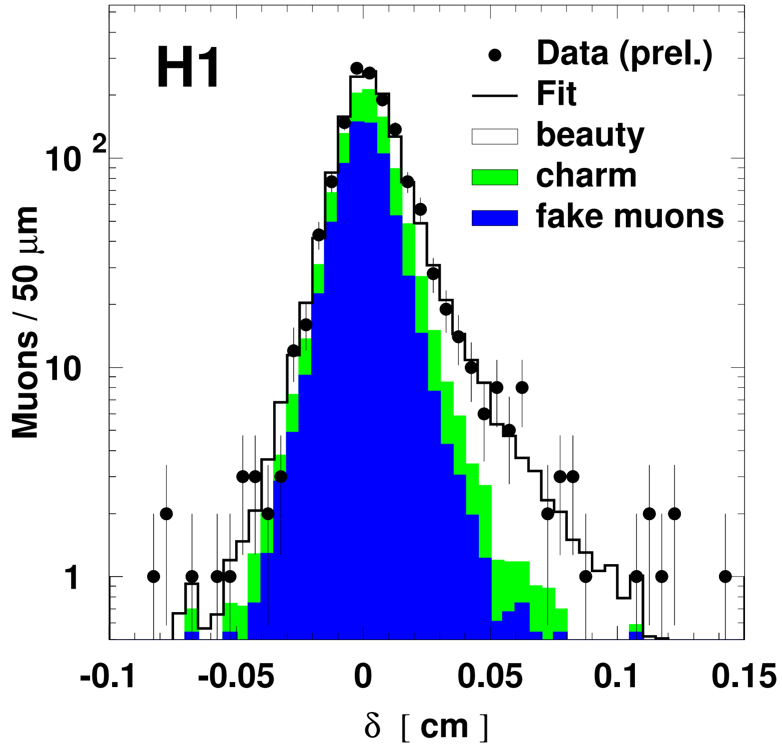


- impact parameter

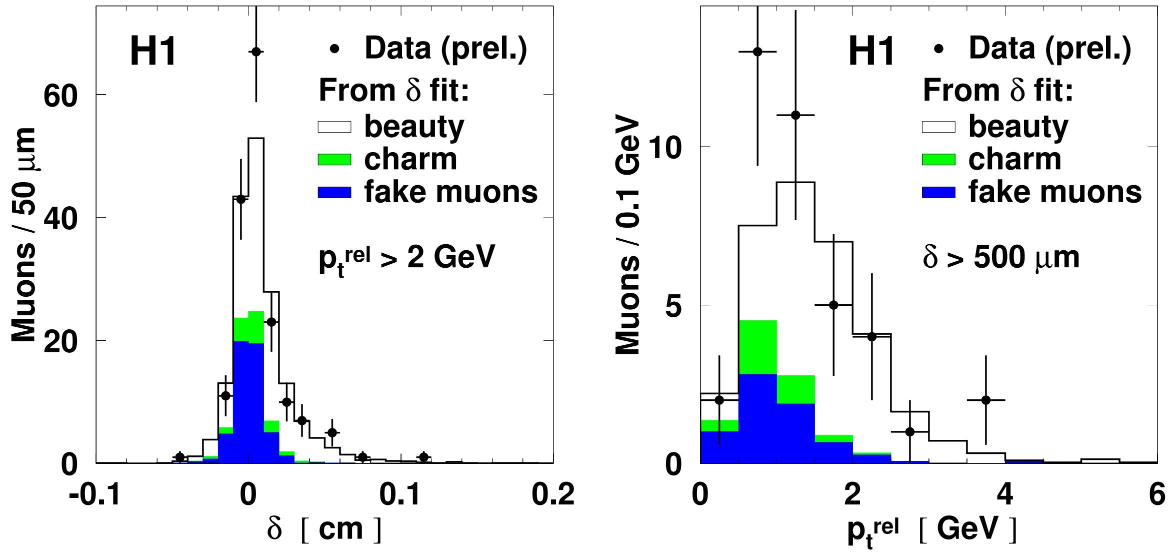


Establish Method in Photopoduction

- ≥ 2 jets $E_T > 5$ GeV,
  ≥ 1 μ in Si tracker



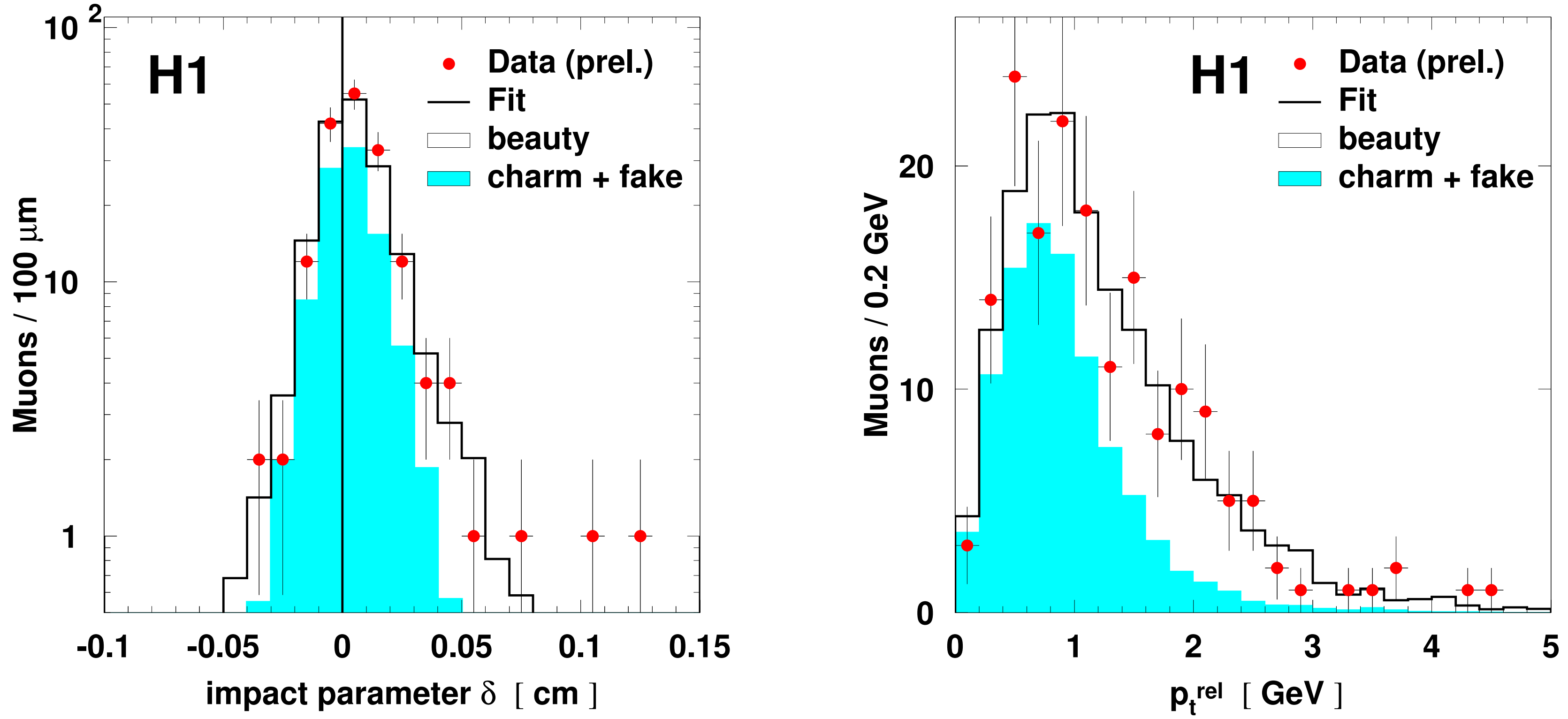
- High b purity regions



$\rightarrow$ do combined likelihood fit in (δ, p_T^{rel}) plane

- b fraction from Likelihood fit: agrees with p_T^{rel} method
- cross section agrees with publ. H1 result

First Measurement of Beauty in DIS



- Kinematic range $2\ \mathrm{GeV}^2 < Q^2 < 100\,\mathrm{GeV}^2,\ 0.05 < y < 0.7$
  (μ and jets as in γp)
  171 candidates in 11 pb^{-1}
- Combined 2D fit $\rightarrow$ $f_b = (43 \pm 8)\,\%$

Visible b Cross Section in DIS

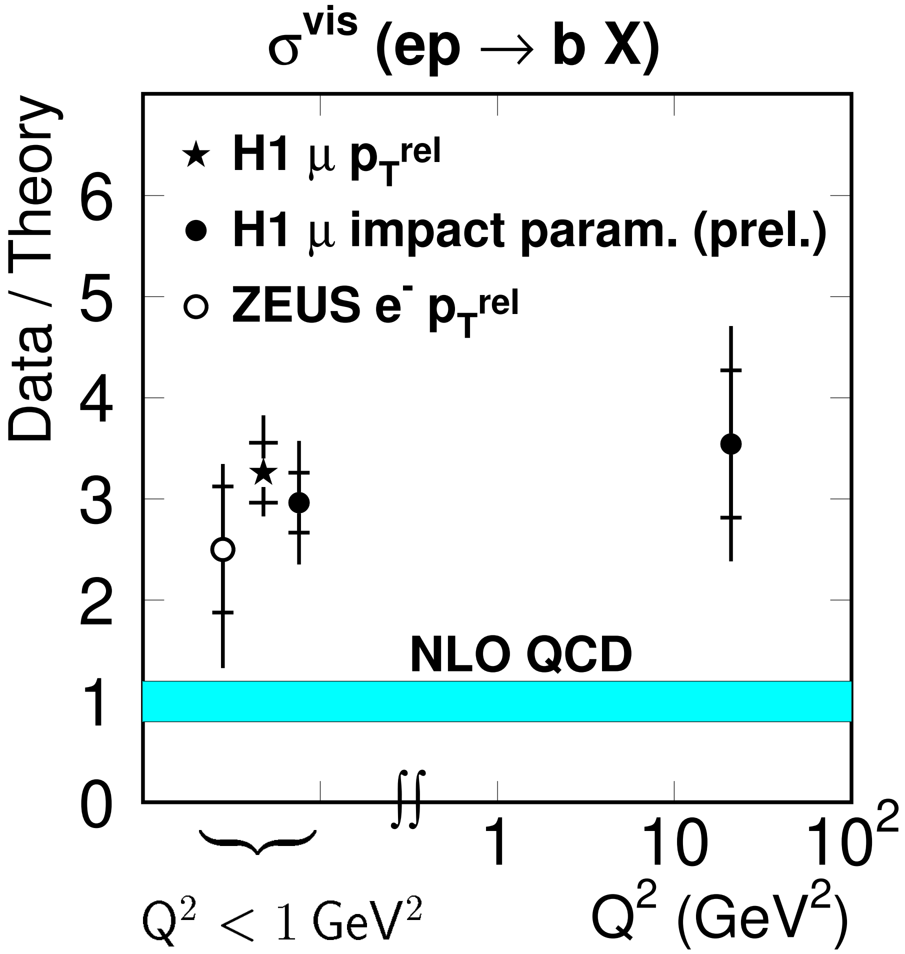
- Kinematic range defined by Q^2, y
  and muon cuts $p_T(\mu) > 2$ GeV, $35^\circ < \theta < 130^\circ$

  $\sigma_{vis}^{ep \to b\bar{b}X \to \mu X} = 39 \pm 8_{stat} \pm 10_{syst}$ pb

- NLO QCD ($m_b = 4.75$ GeV): $\sigma = 11 \pm 2$ pb

- LO MC:
  AROMA (Altarelli-Parisi evolution): $\sigma = 9$ pb
  CASCADE (CCFM evolution, k_t-dependent gluon): $\sigma = 15$ pb

Beauty Summary:



- σ_B at HERA exceeds NLO QCD
  – also in DIS
- More surprises in the Beauty Case than in the Charm Case