Charm and Beauty Production at HERA

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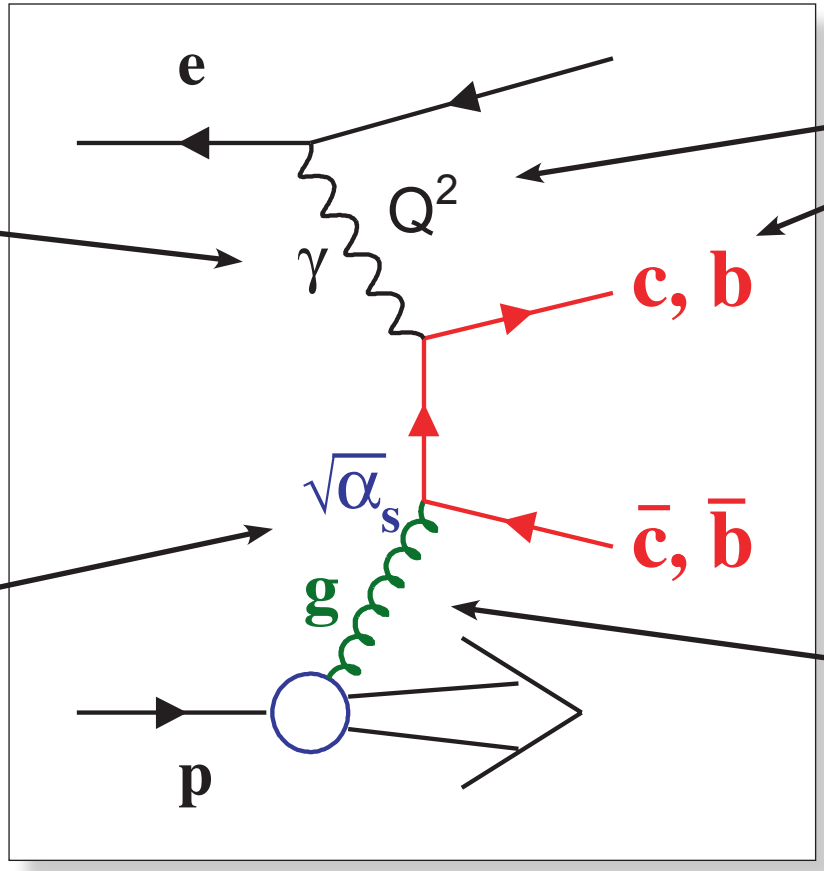
Content:

- Introduction
- Charm production
- Beauty production
- Structure functions
- Summary

Heavy Flavour Production

Boson Gluon Fusion
main production process



- hadronic structure of the photon
- investigate multi-scale problem: Q^2, p_t, $m_{c/b}$
- at least one hard scale -> α_s small
- test different pQCD models and schemes
- direct sensitive to gluon density of proton

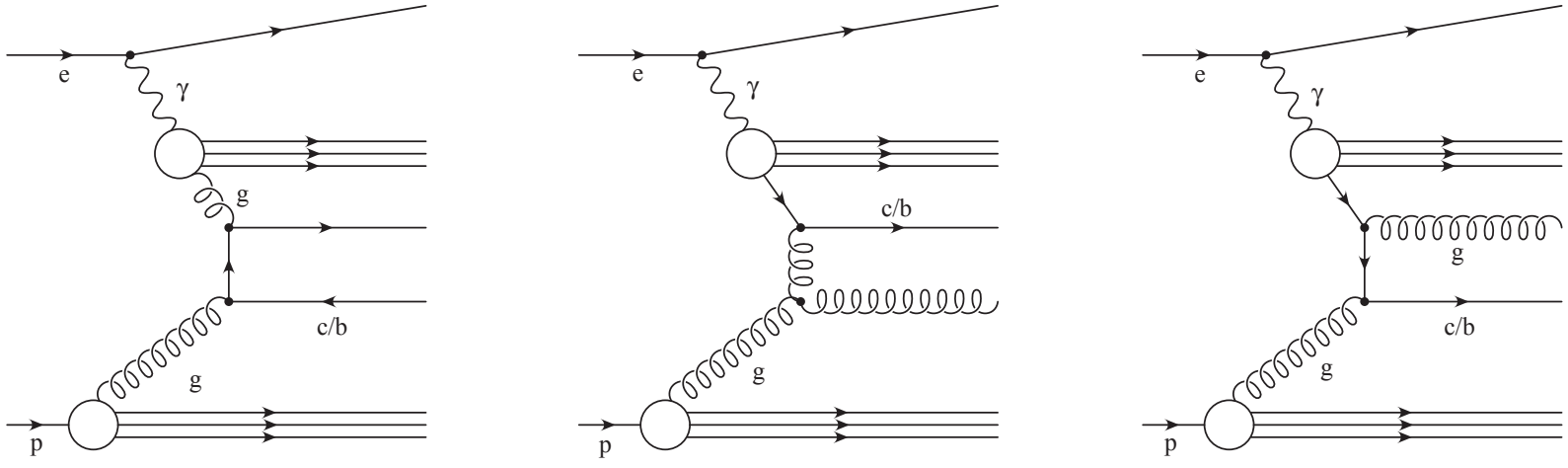
Further Contributions

two kinematic regions:

- photoproduction (γp): $Q^2 < 1\ GeV^2$
- deep inelastic scattering (DIS): $Q^2 > 2\ GeV^2$

for DIS: Boson Gluon Fusion dominates (@LO)

for γp: also significant contribution from resolved photon:

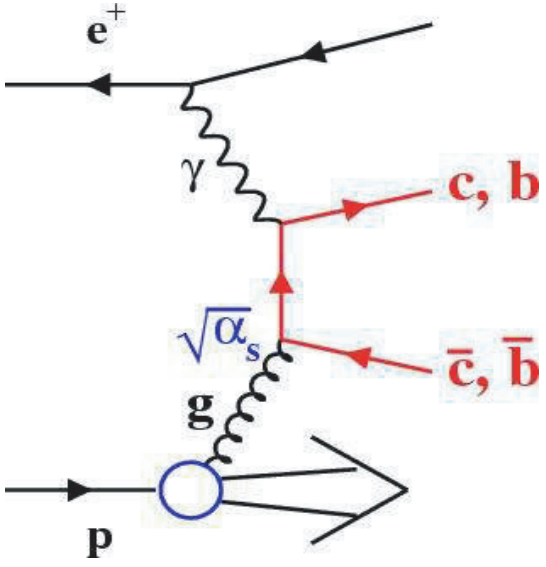


- x_γ^{obs}: momentum fraction of parton entering the hard process from photon side

Theoretical Approaches

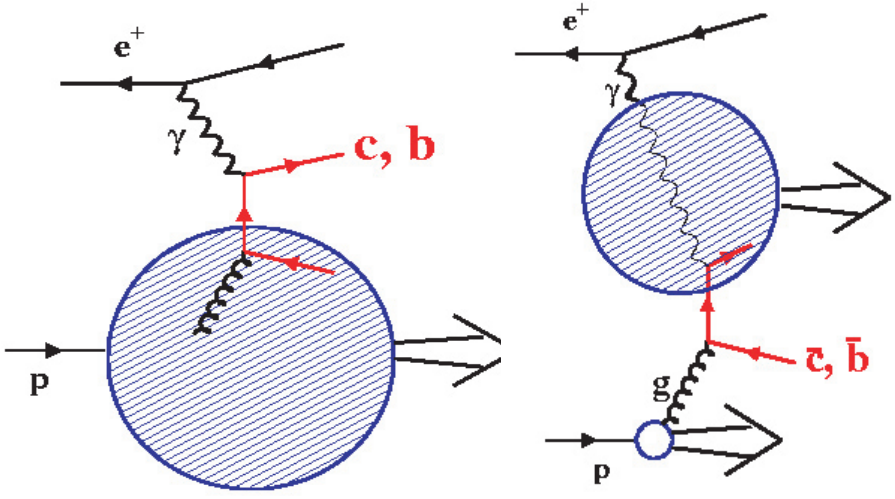
Massive scheme:

- fixed order calculation
- heavy quarks are produced in the hard process
- neglecting: $\left[\alpha_s \ln(Q^2/m_c^2)\right]^n$
- valid at: $m^2_{c/b} \sim Q^2$



Massless scheme:

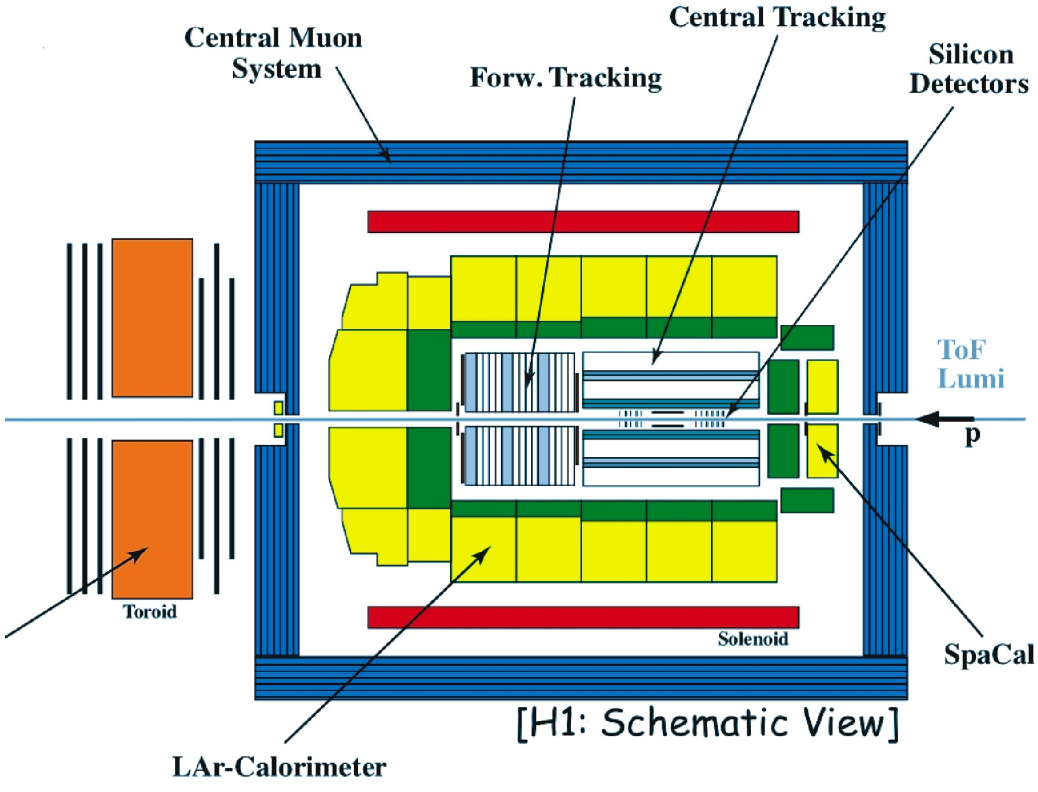
- heavy quarks are an intrinsic content of the proton and photon
- Resums: $\left[\alpha_s \ln(Q^2/m_c^2)\right]^n$
- valid at: $m^2_{c/b} << Q^2$

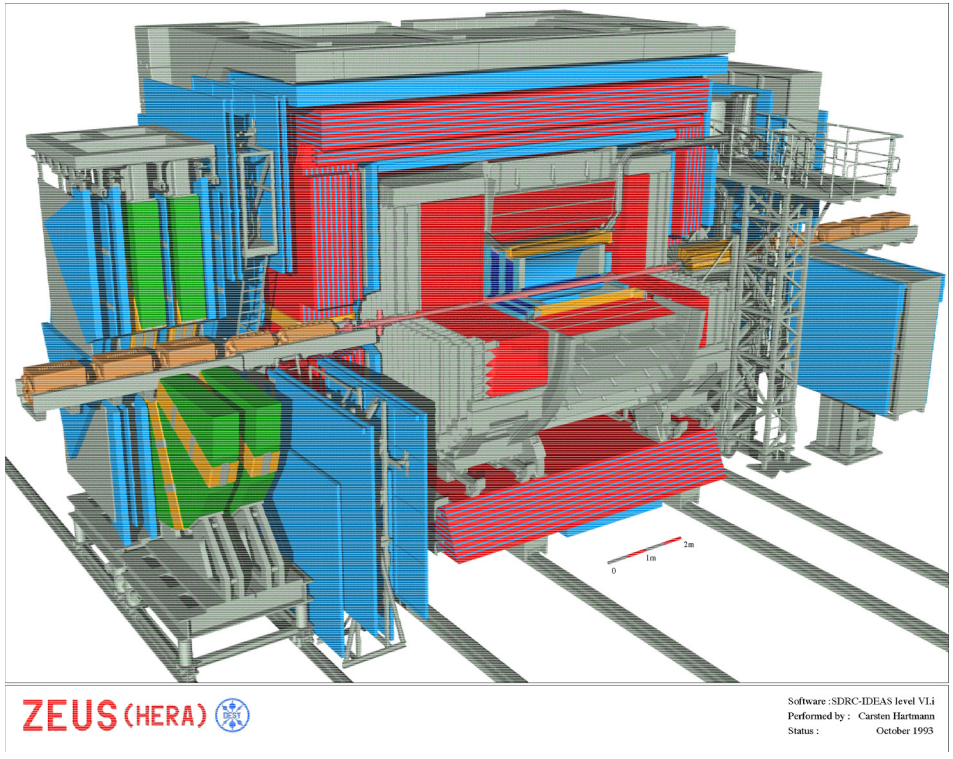


Intermediate (variable) schemes:

low Q^2: massive scheme
intermediate Q^2: interpolate
high Q^2: massless scheme

Experiments: H1 and Zeus





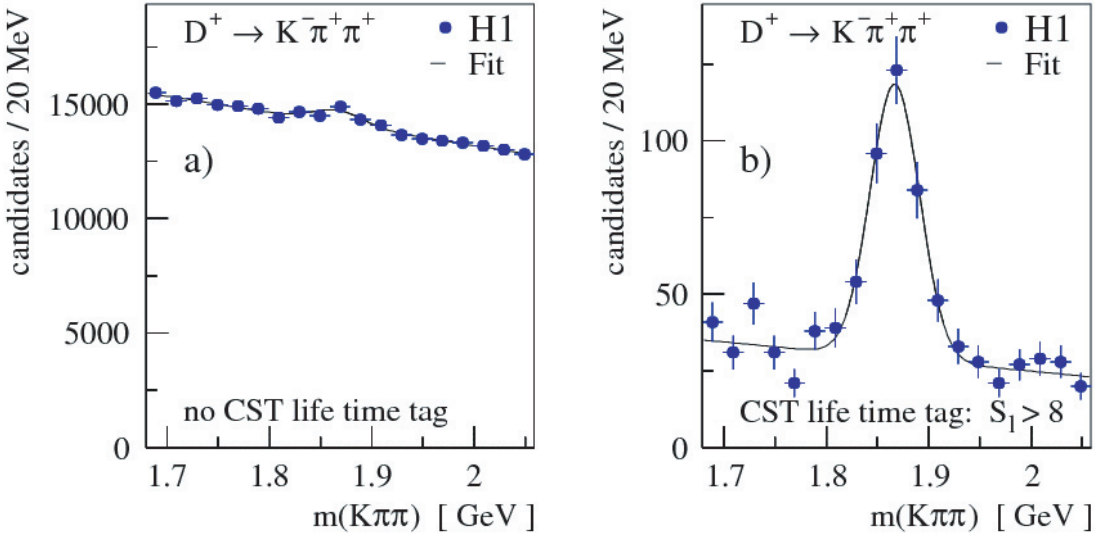
- 27.5 GeV e^- on 920 GeV p => $\sqrt{s}$ = 320 GeV
- detectors have nearly 4π coverage
- most relevant detectors:

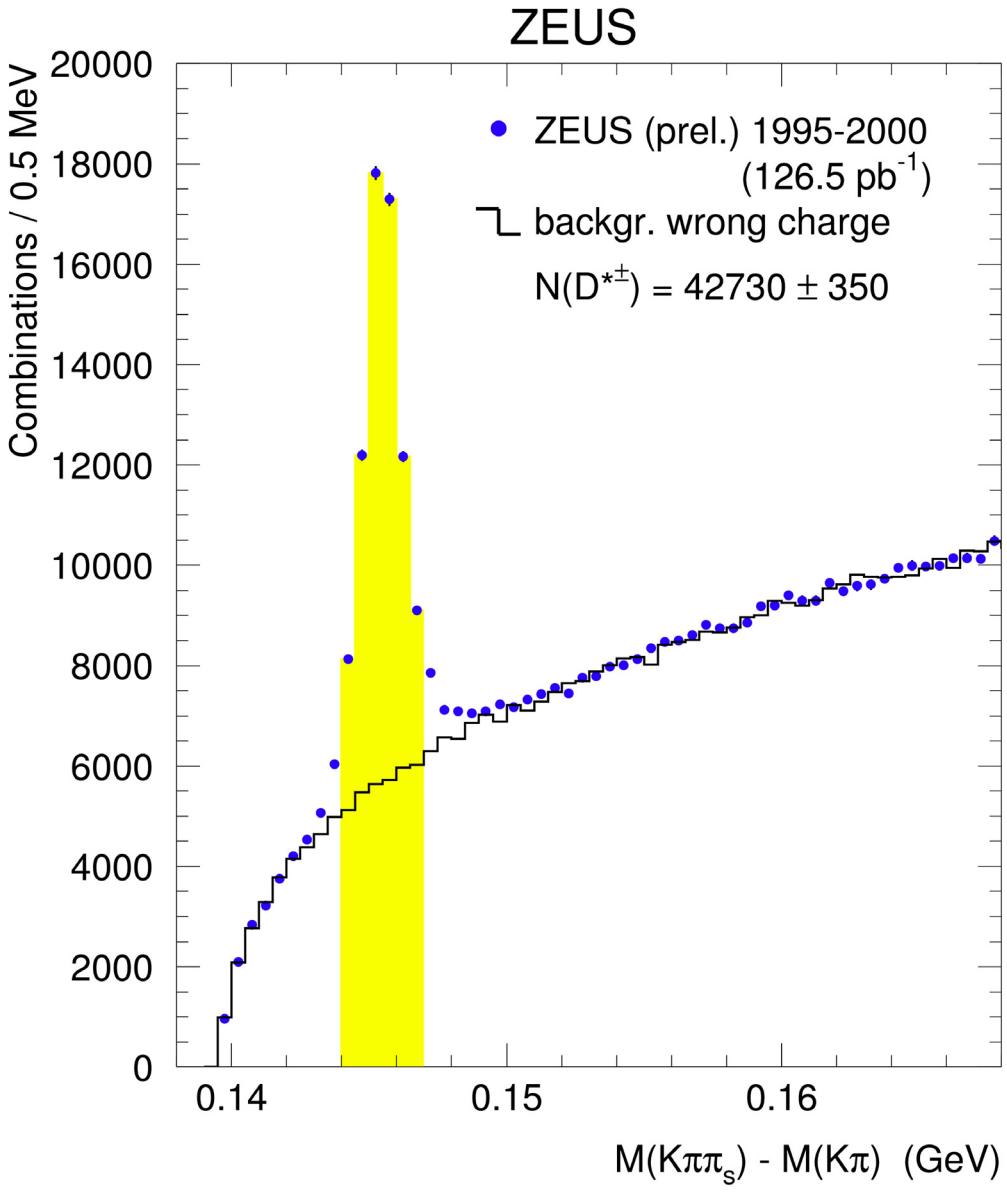
  muon chamber, tracking and vertex detectors

Charm Tagging

- Via resonance reconstruction - e.g. D*: $D^{\star} \rightarrow D^{0}\,\pi_{slow} \rightarrow K\,\pi\,\pi_{slow}$
- Plot: $\Delta M = M(K\,\pi\,\pi_{slow}) - M(K\,\pi)$

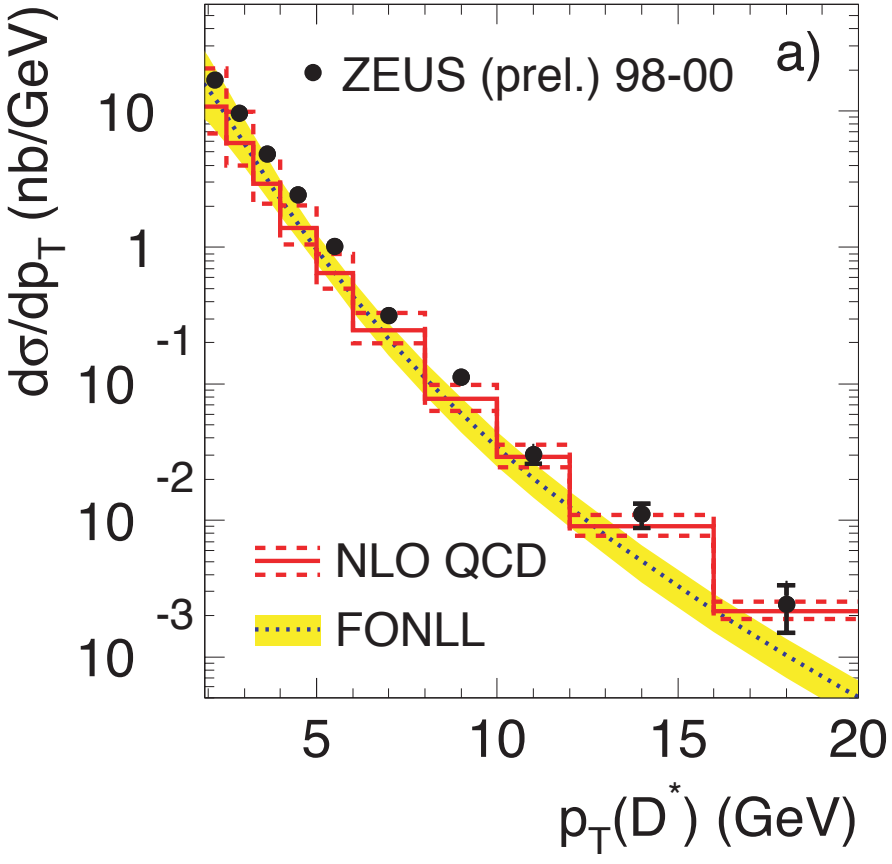
- Via lifetime tagging using a silicon vertex detector

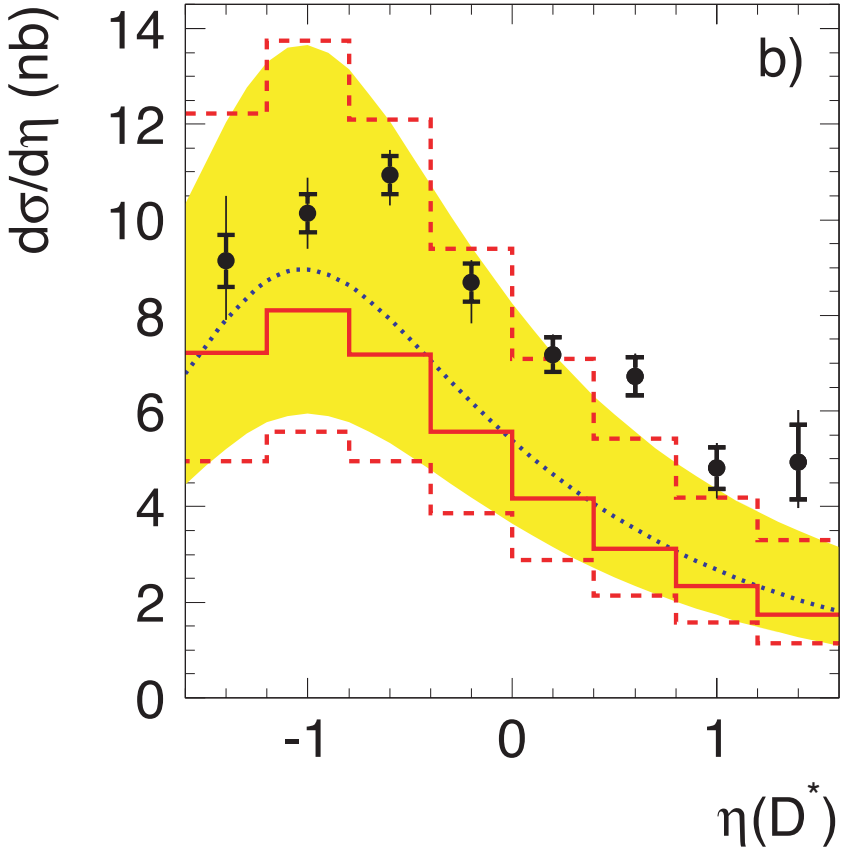




D* production in γp

ZEUS



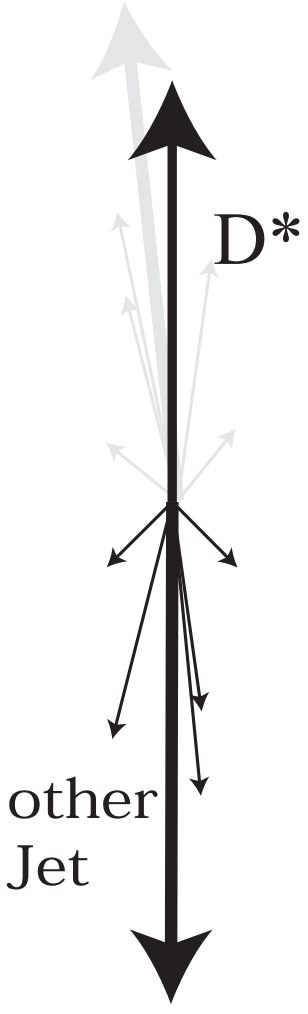


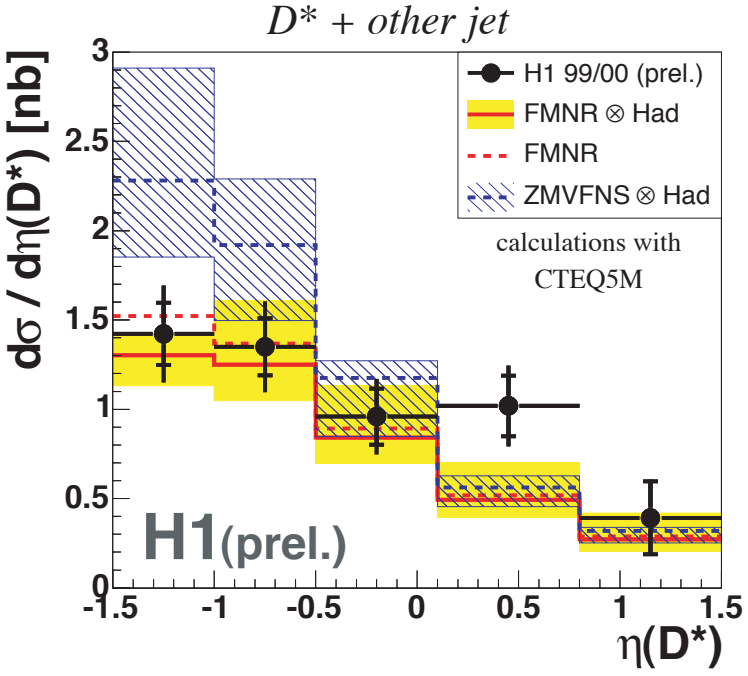
massive NLO: reasonable agreement

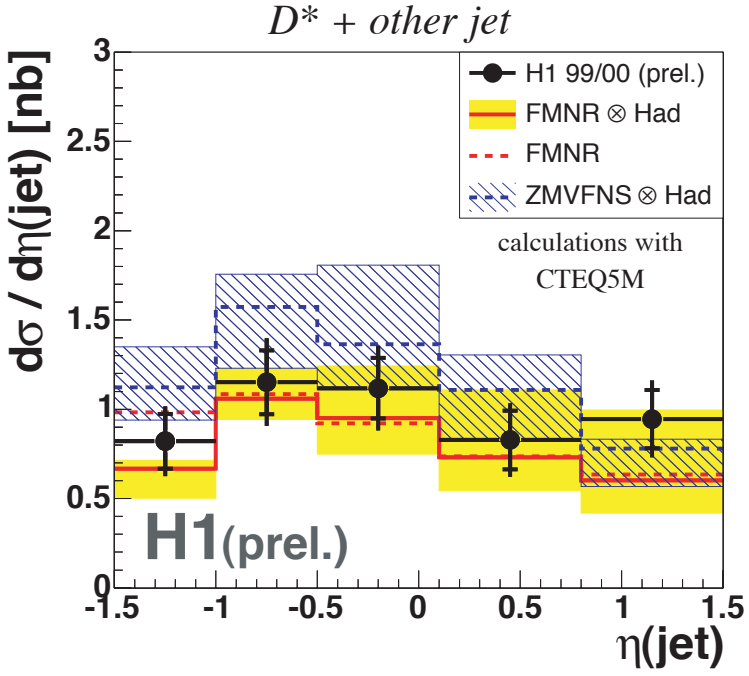
massless NLO: at high p_t it seems low

- soft scales => large errors in NLO calculations (p_t ~ 3 GeV)
- data tends to be more forward

D* + jet production in γp





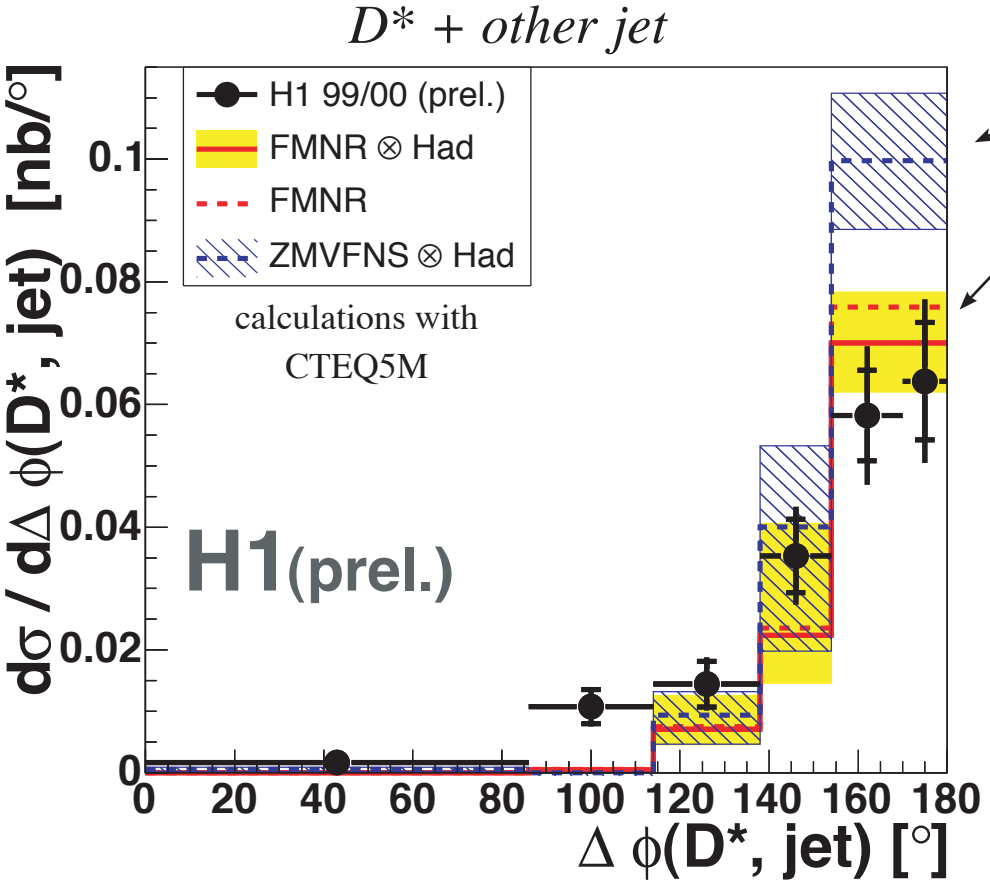


- D*+Jet: possibility to study further details of charm production
- D* -> kinematics of the charm quark
- Jet -> kinematics of another parton, either other c-quark, light quark or gluon

overall nice agreement between data and theory

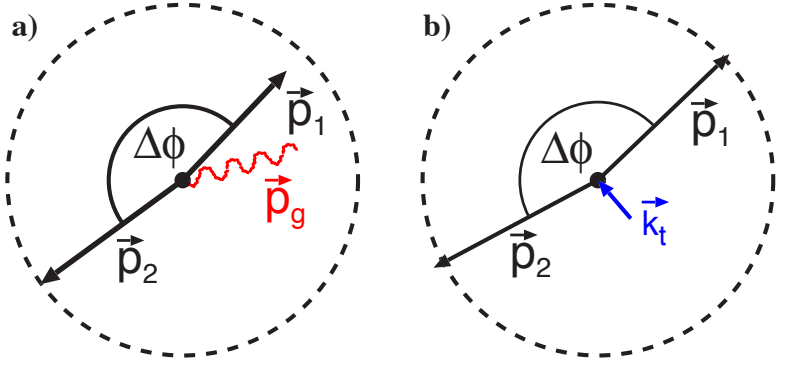
D* + jet production (ii)

Study azimutal correlation of D* and the jet: $\Delta\Phi(D^*, \mathrm{Jet})$



massless

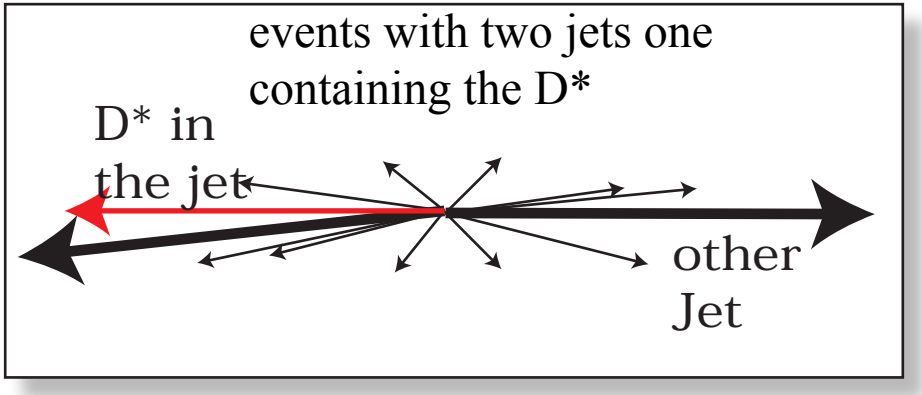
massive



Gluon radiation or initial parton k_t can lead to non back to back topologies

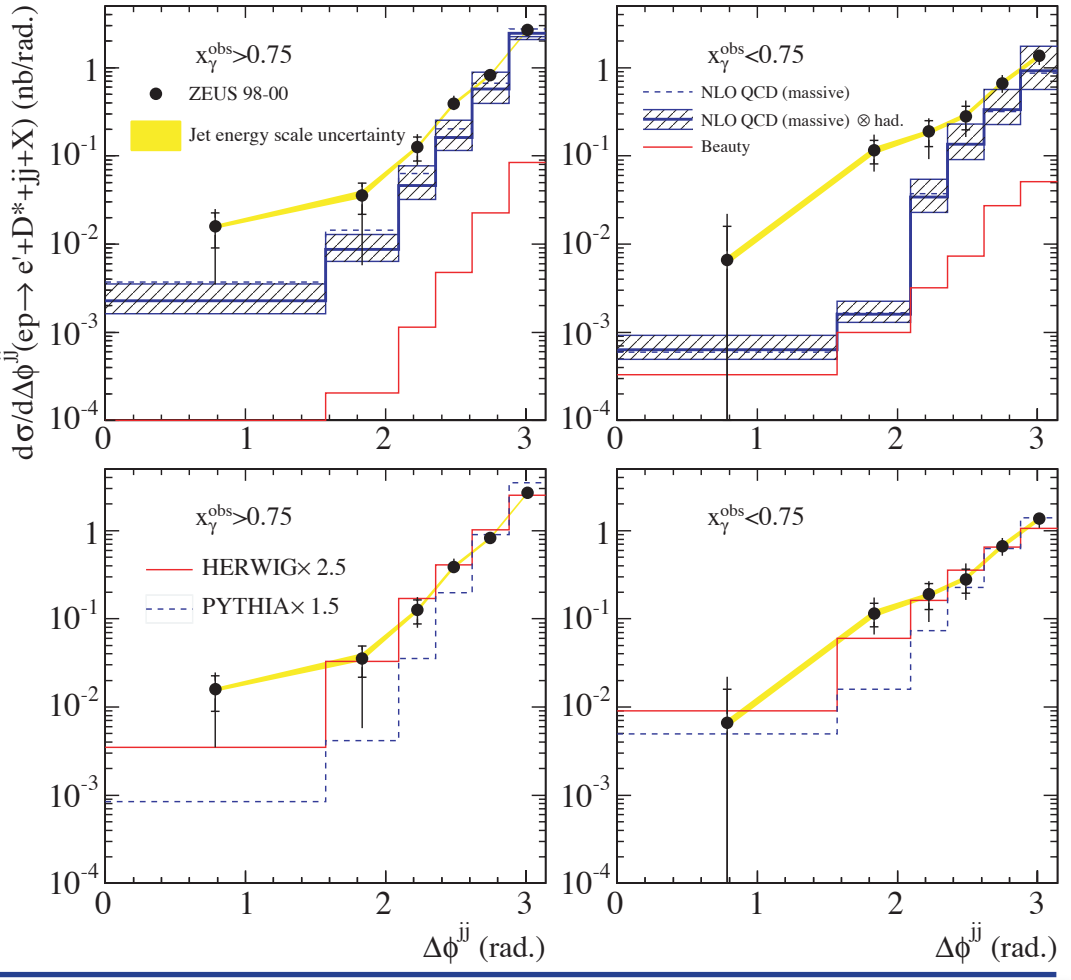
=> Data indicates higher order contributions

Charm Dijet Production in γp



direct enriched $x_\gamma^{obs} > 0.75$

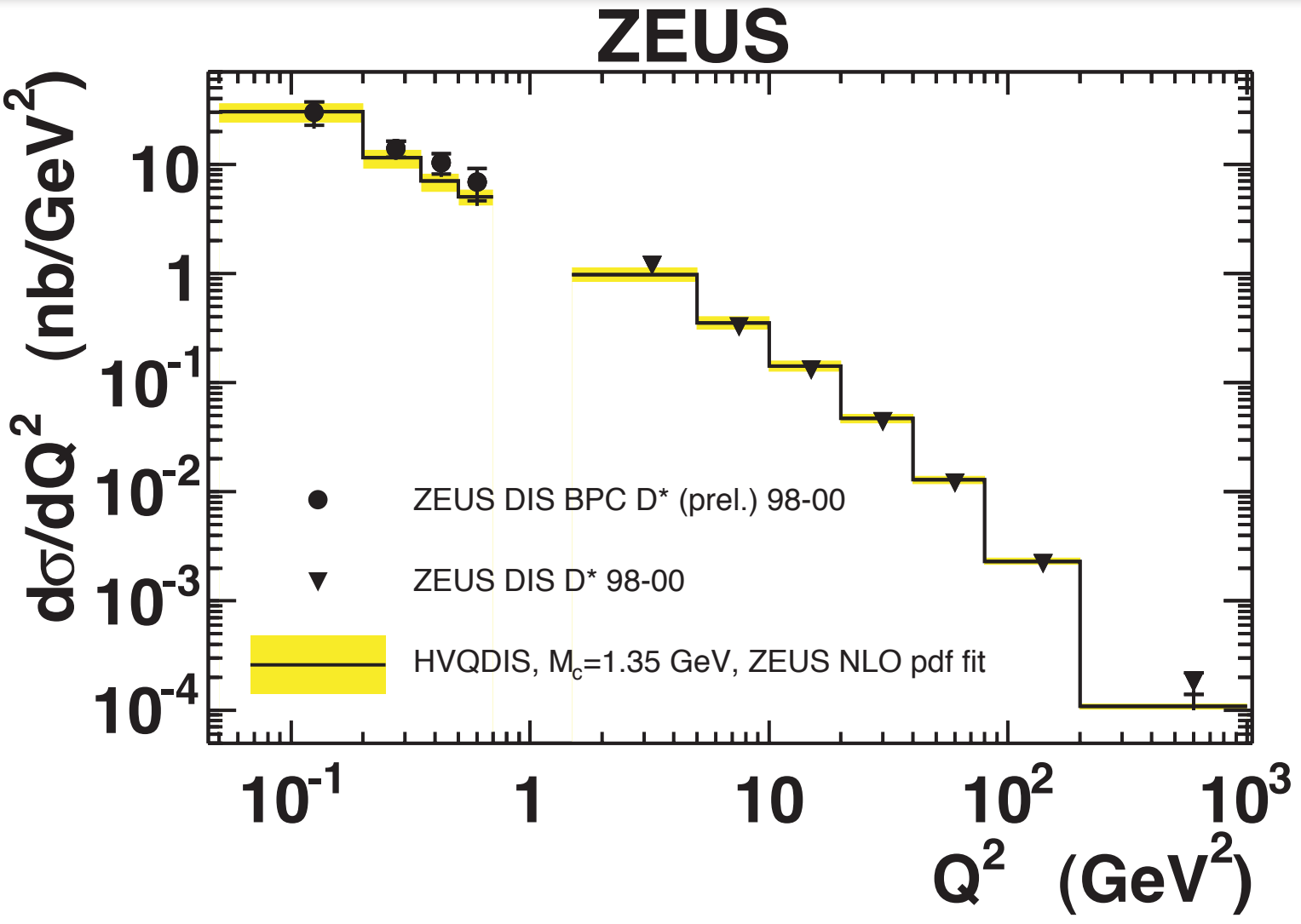
resolved enriched $x_\gamma^{obs} < 0.75$



- direct softer than resolved
- resolved data harder than massive NLO calculation
- LO-MC + PS is able to describe the data

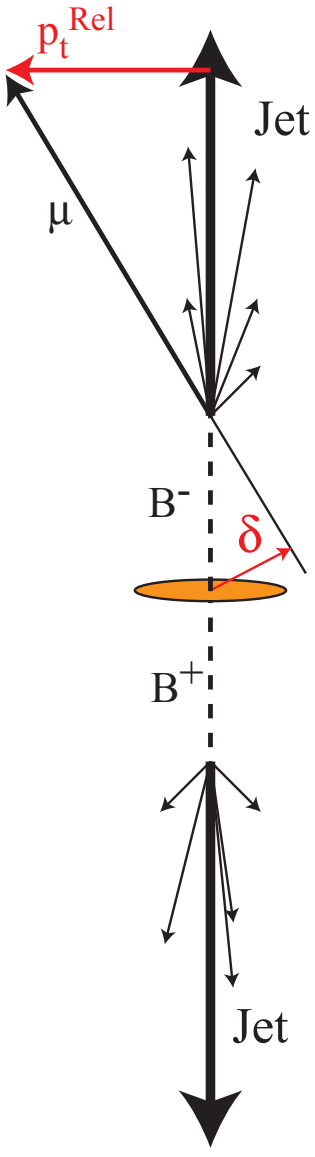
=> resolved region indicating higher order effects?

D* Production from γp to DIS

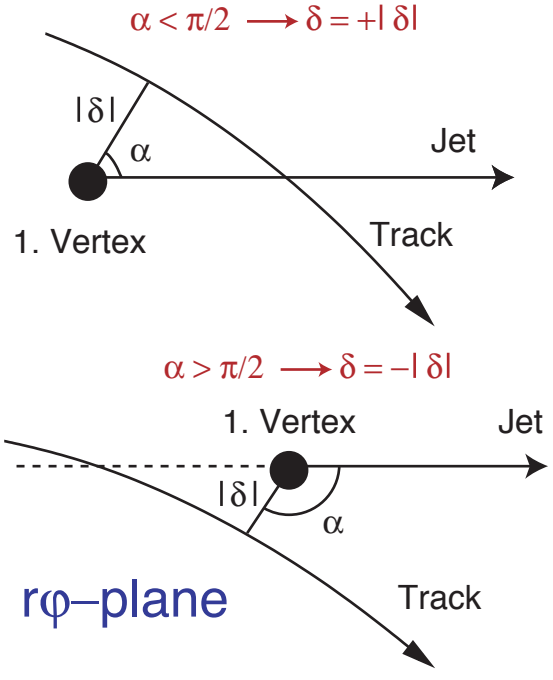


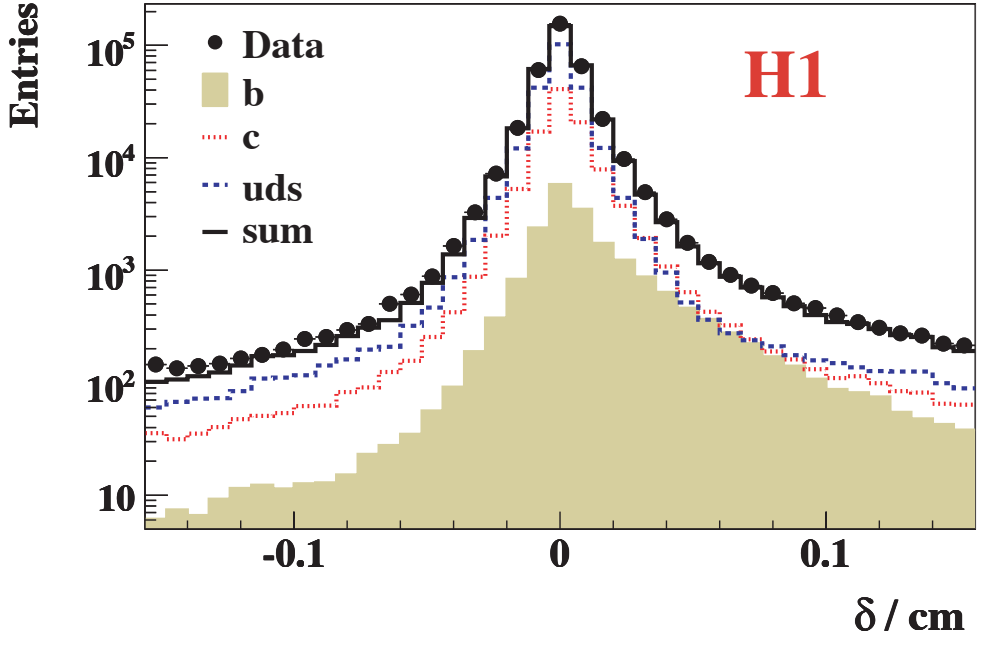
very good agreement over a large Q^2 range!

Beauty Tagging



- p_t^{Rel}-method:
  - process: $ep \rightarrow eb\bar{b}X \rightarrow ejj\mu X$
  - large beauty mass causes a large p_t relative to the corresponding jet
- impact parameter method:
  - long lifetime of the b-Mesons causes a large positive impact parameter δ



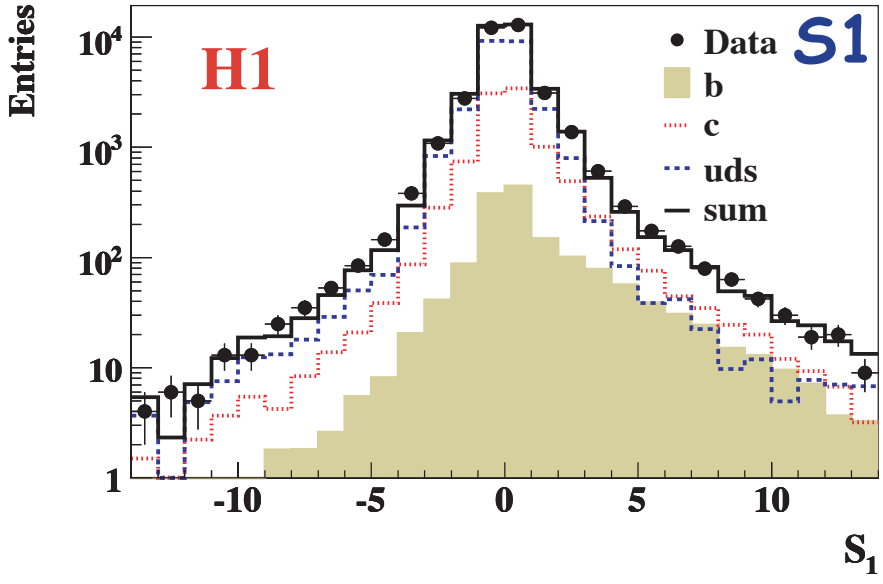


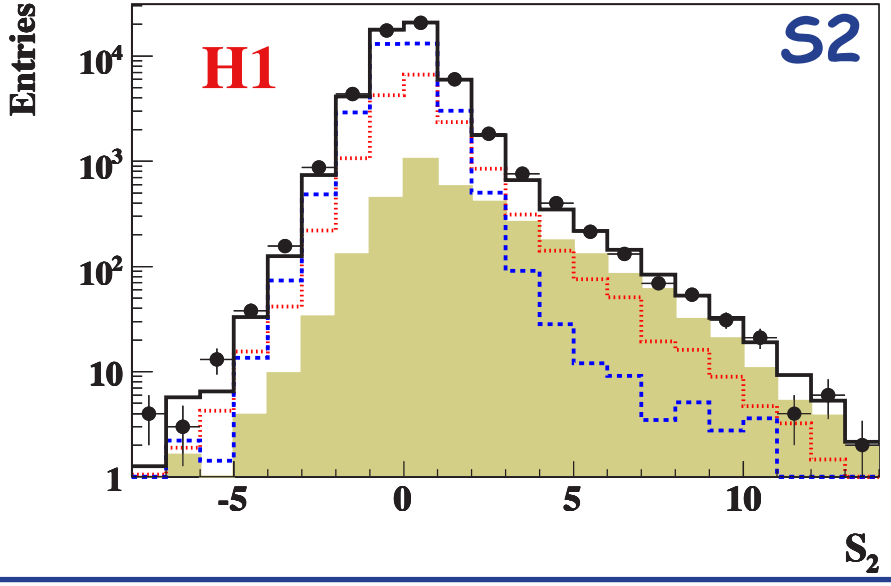
Inclusive Lifetime Analysis

- use significance of signed impact parameter: $S = \frac{\delta}{\sigma(\delta)}$
- **S1** signif. of highest significance track
- **S2** signif. of 2nd highest significance track with same sign as **S1**

- **S2**: large contributions from charm and beauty for high **S2**
- fit to data using mc as templates

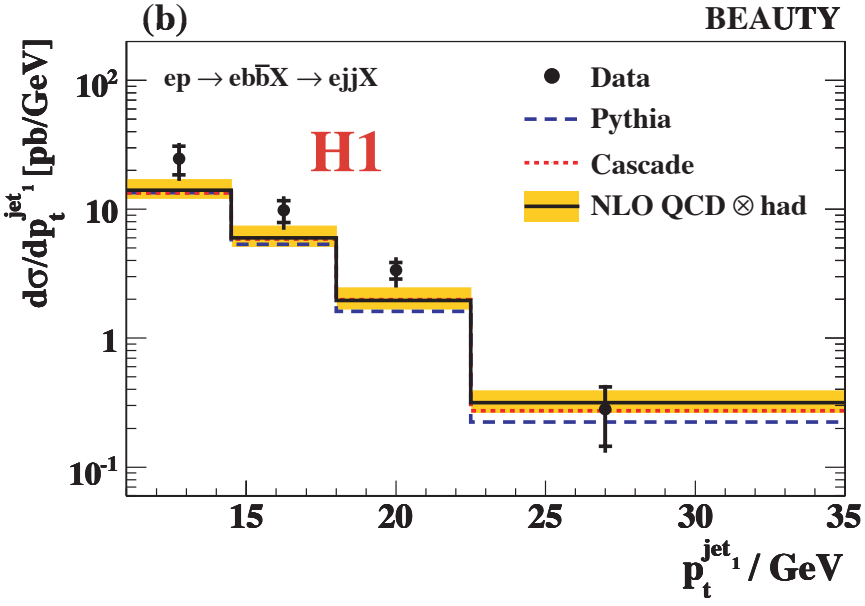
=> measure charm and beauty simultaneously

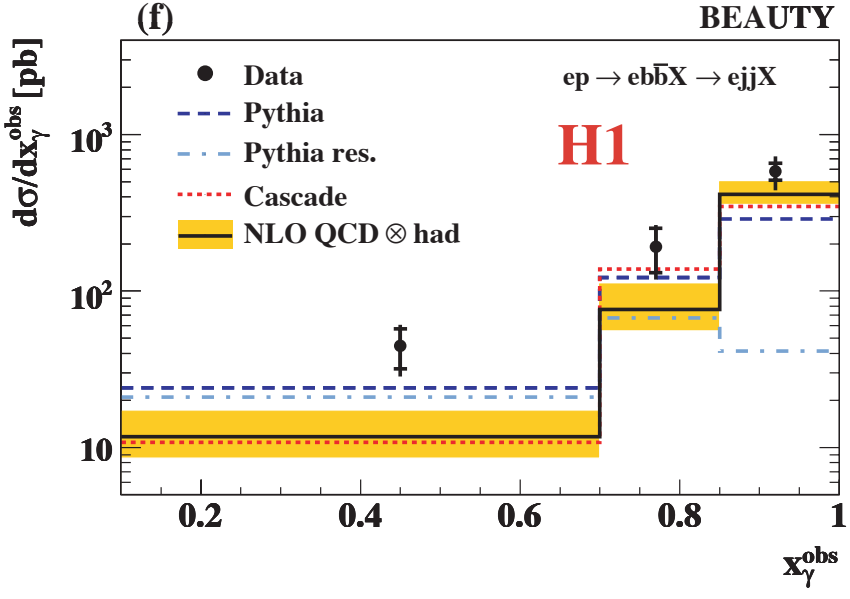




Beauty Production in γp

- select dijet events in γp
- shape is reasonably well described
- tendency that massive calculation falls below the data
- some deviation of massive calculation at low x_γ^{obs}
- large resolved component as predicted by PYTHIA



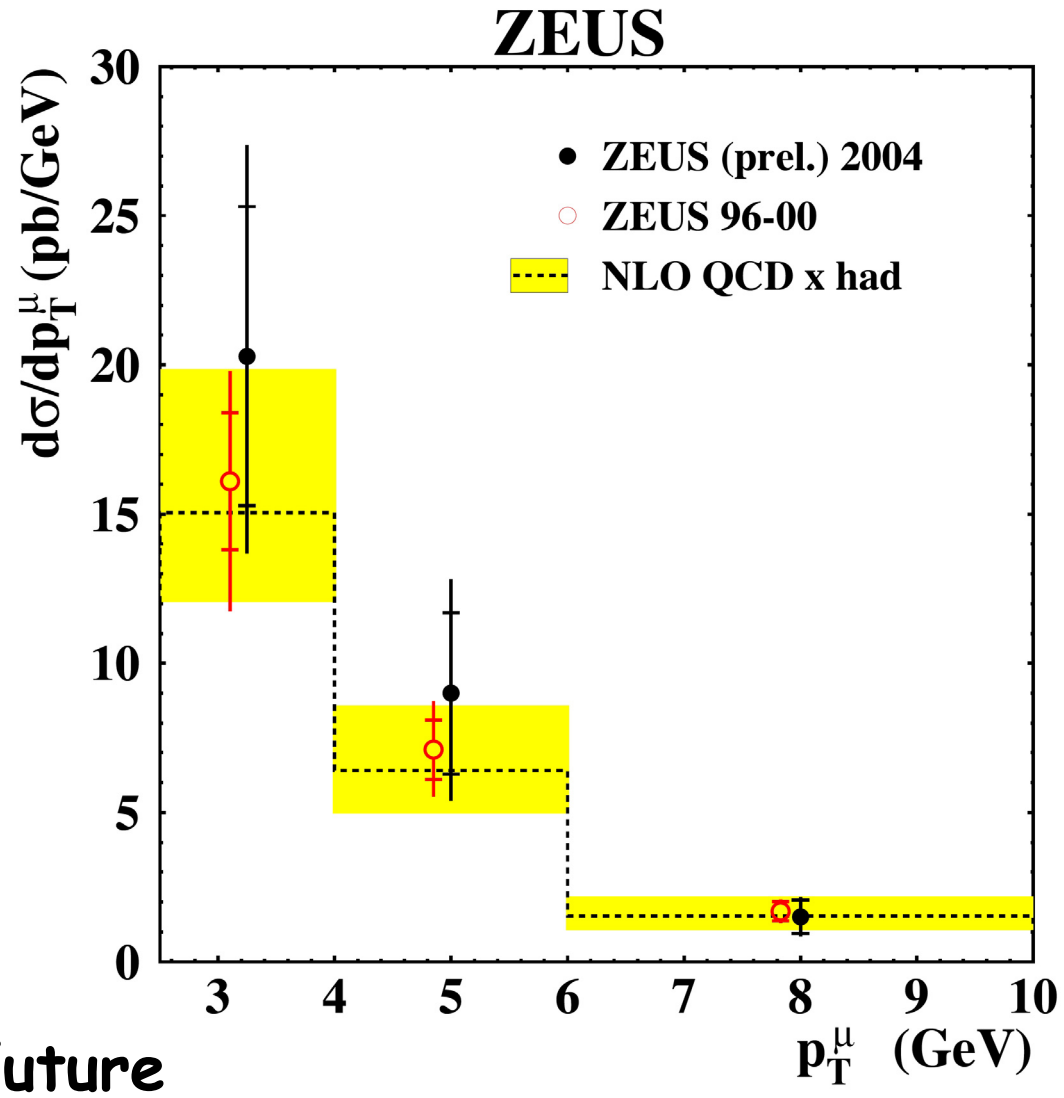


hep-ex/0605016 H1-153

μ + Jets

Measured process: $ep \to eb\bar{b}X \to ejj\mu X$

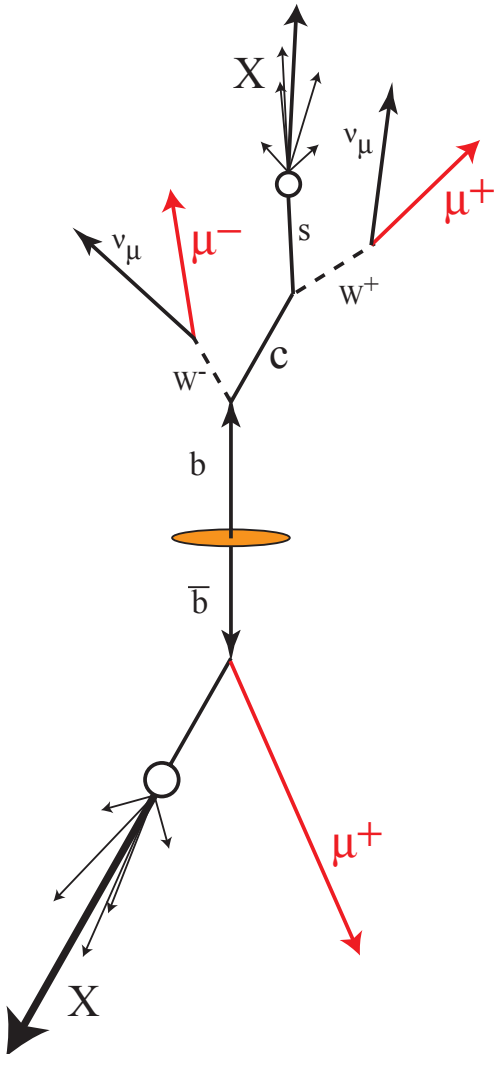
- first use of newly installed silicon vertex detector (MVD)
- simultaneous use of the impact parameter- and the p_t^{Rel}-method
- good agreement between HERA I and II data and massive NLO calculation



- first HF-HERA II result!
- using only 33pb^{-1} of ~230pb^{-1}

=> much more to come in the future

Double Tagging



Method:

- same hemisphere: 2 unlike signed μ‘s
- opposite hemisphere: 2 μ‘s with like or unlike sign
- background has always uncorrelated charge signs
- subtraction of like from unlike sign μ

=> very pure b sample

Advantages:

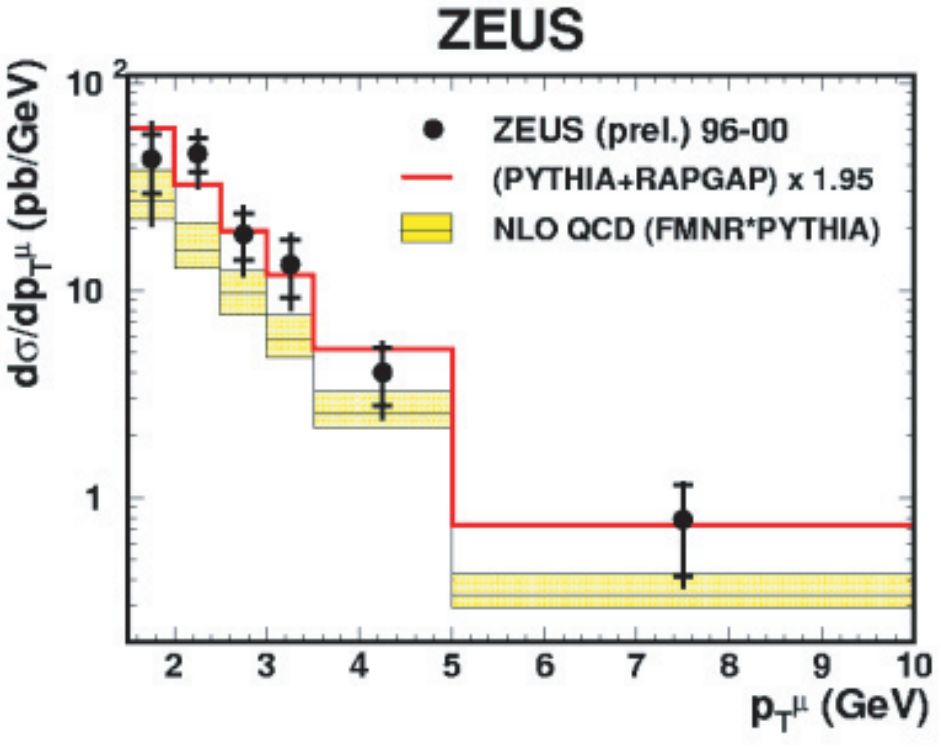
- low background
- soft kinematic cuts

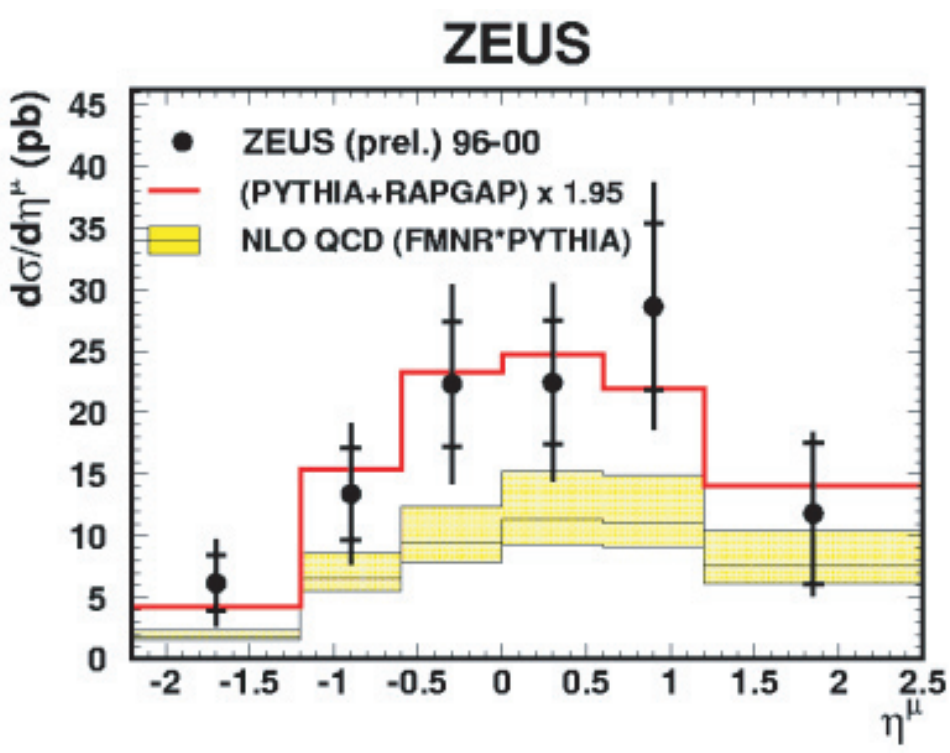
=> access to low p_t of b quarks

- almost full η coverage
- allows analysis of the correlation between the b-quarks

=> measurement of total b x-section with almost no extrapolation

DiMuon Tagging

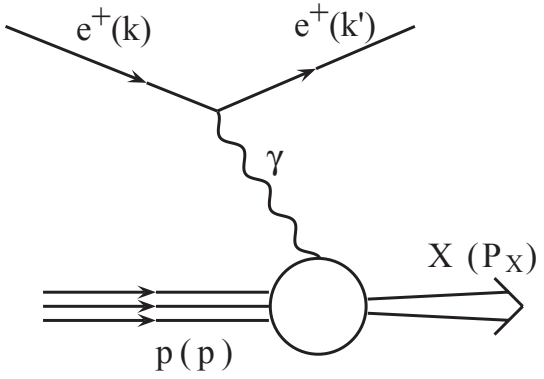




- new FMNR-PYTHIA interface now allows calculation of complicated visible NLO cross sections
- shape reasonably well described by MC and theory
- data tends to be higher than massive NLO calculation
- total cross-section: $\sigma_{\mathrm{tot}}(ep \to b\bar{b}X) = 16.1 \pm 1.8(\mathrm{stat.})^{+5.3}_{-4.8}(\mathrm{syst.})$ nb

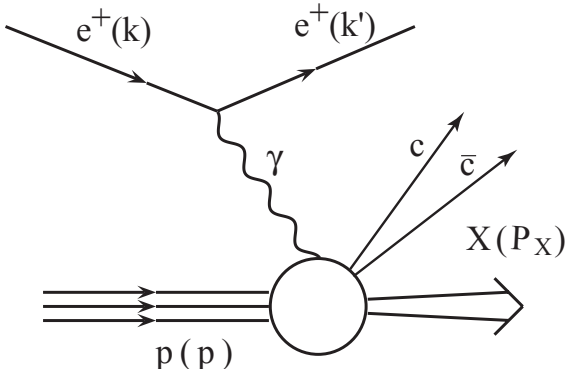
Proton-Structure Function F_2

Inclusive ep-scattering:



$$\frac{d^2\sigma^{ep}}{dQ^2dx} \propto F_2(Q^2, x)$$

Contribution of c and b to inclusive F_2:



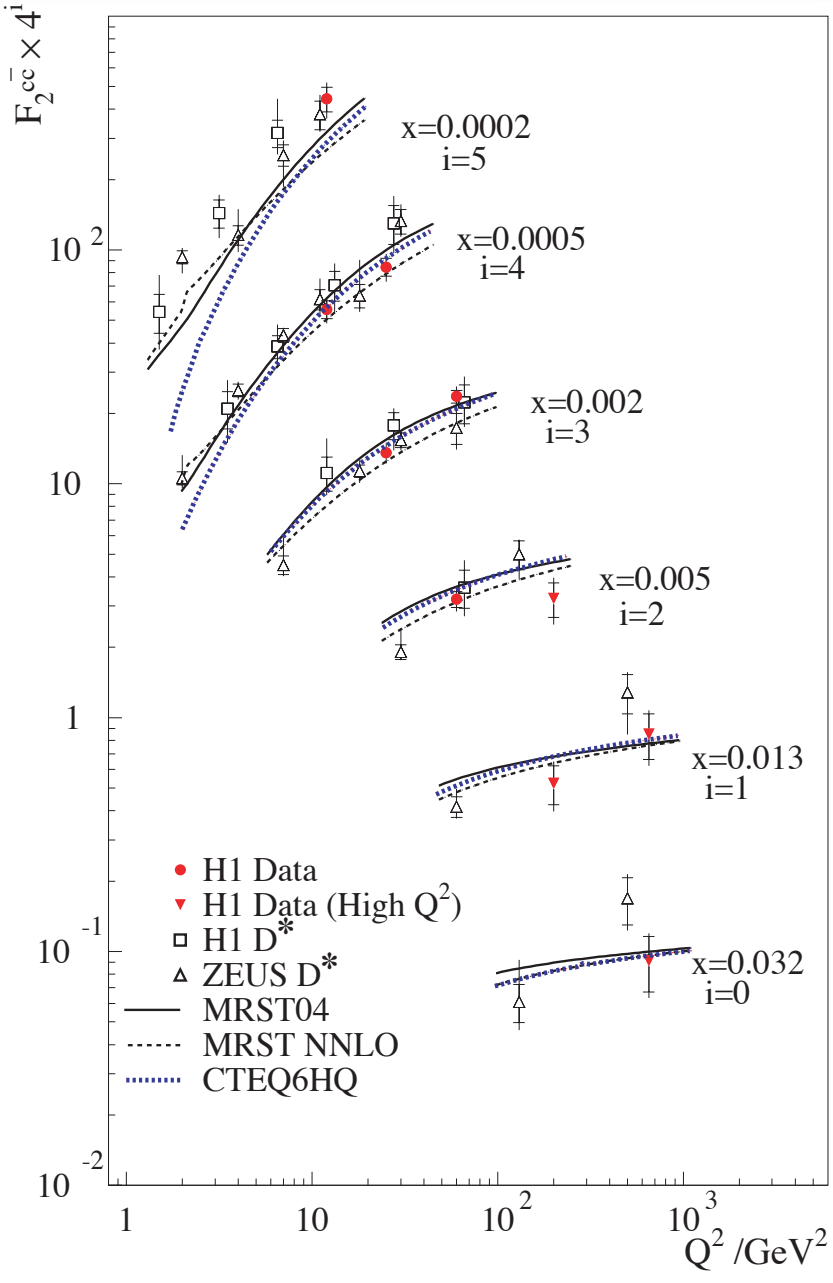
$$\frac{d^2\sigma^{ep\to c\bar{c}X}}{dQ^2dx} \propto F_2^{c\bar{c}}(Q^2, x)$$

similar for F_2^{bb}

$F_2^{cc(bb)}$ is the contribution to F_2 originating from c(b)-quarks

F_2^{cc}

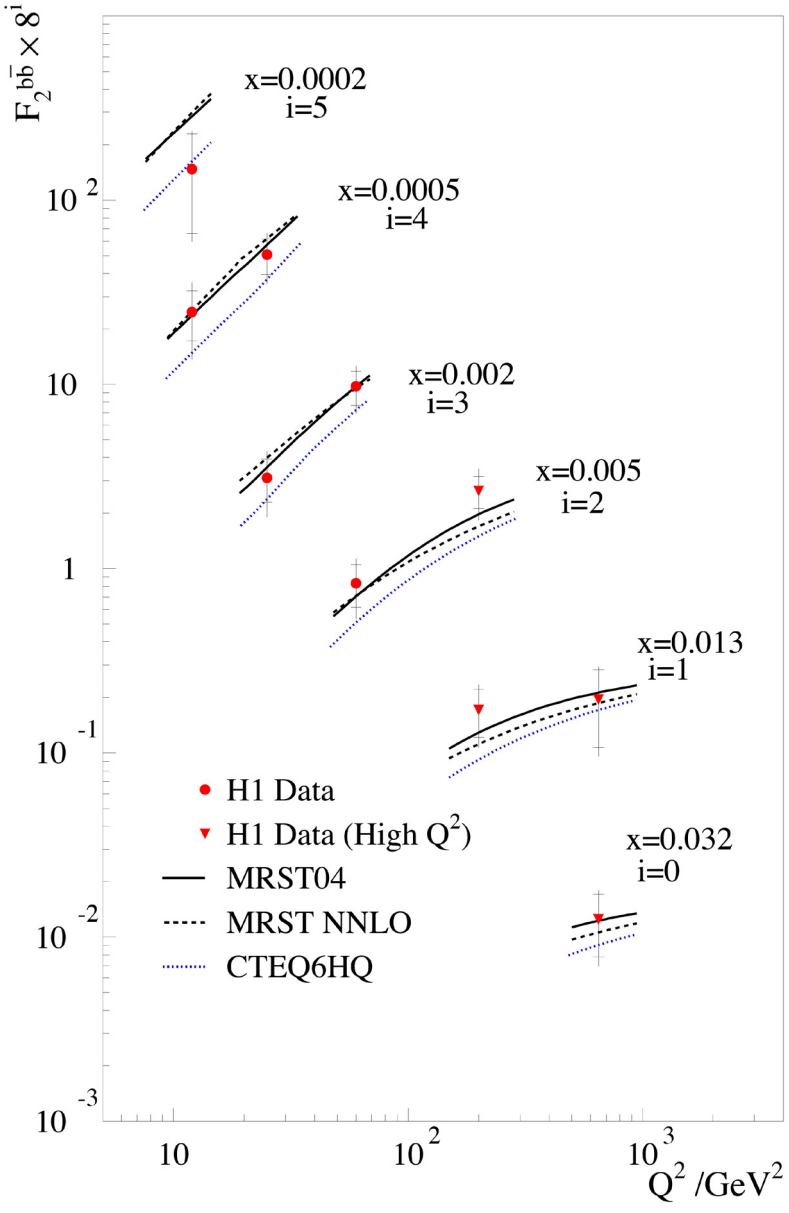
- in red: impact parameter method
- scaling violations
- high precision data => able to distinguish between predictions



A. Aktas et al., Eur. Phys. J. C45 (2006) 23-33
A. Aktas et al., Eur. Phys. J. C40 (2005) 349-359

F_2^{bb}

- first F_2^{bb} measurement at HERA
- statistical errors dominates / low x-section
- data not yet decisive
- update for MRST-NNLO calculation



A. Aktas et al., Eur. Phys. J. C45 (2006) 23-33
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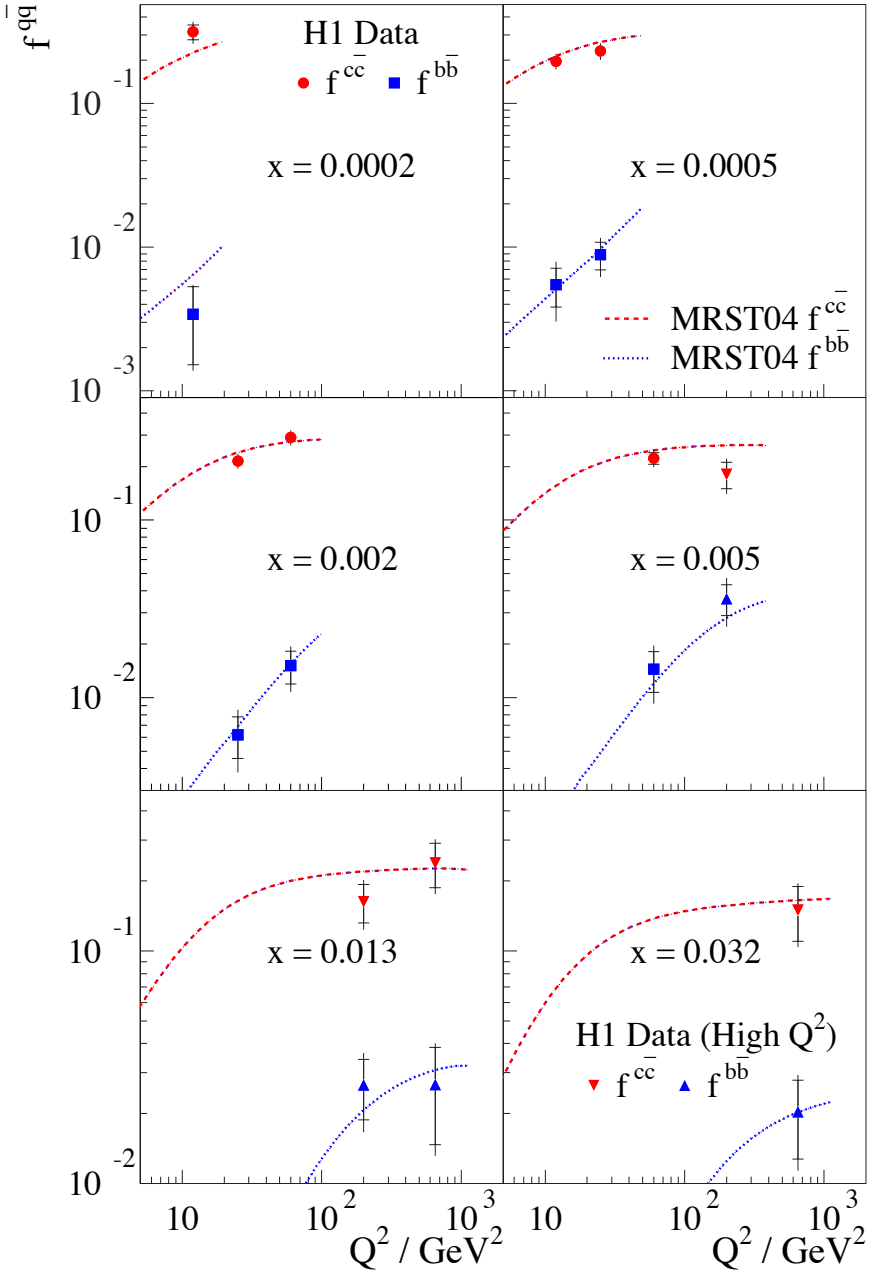
F_2 vs $F_2^{q\bar{q}}$



- F_2^{cc} contribution to F_2: ~ 30%
- F_2^{bb} contribution is marginal
- shapes are different from F_2

Summary

- pQCD (NLO) is able to describe the data

Charm:

- good description achieved with NLO calculations; data more precise than theory
- in some variables deviations seen (higher order effects?)

Beauty:

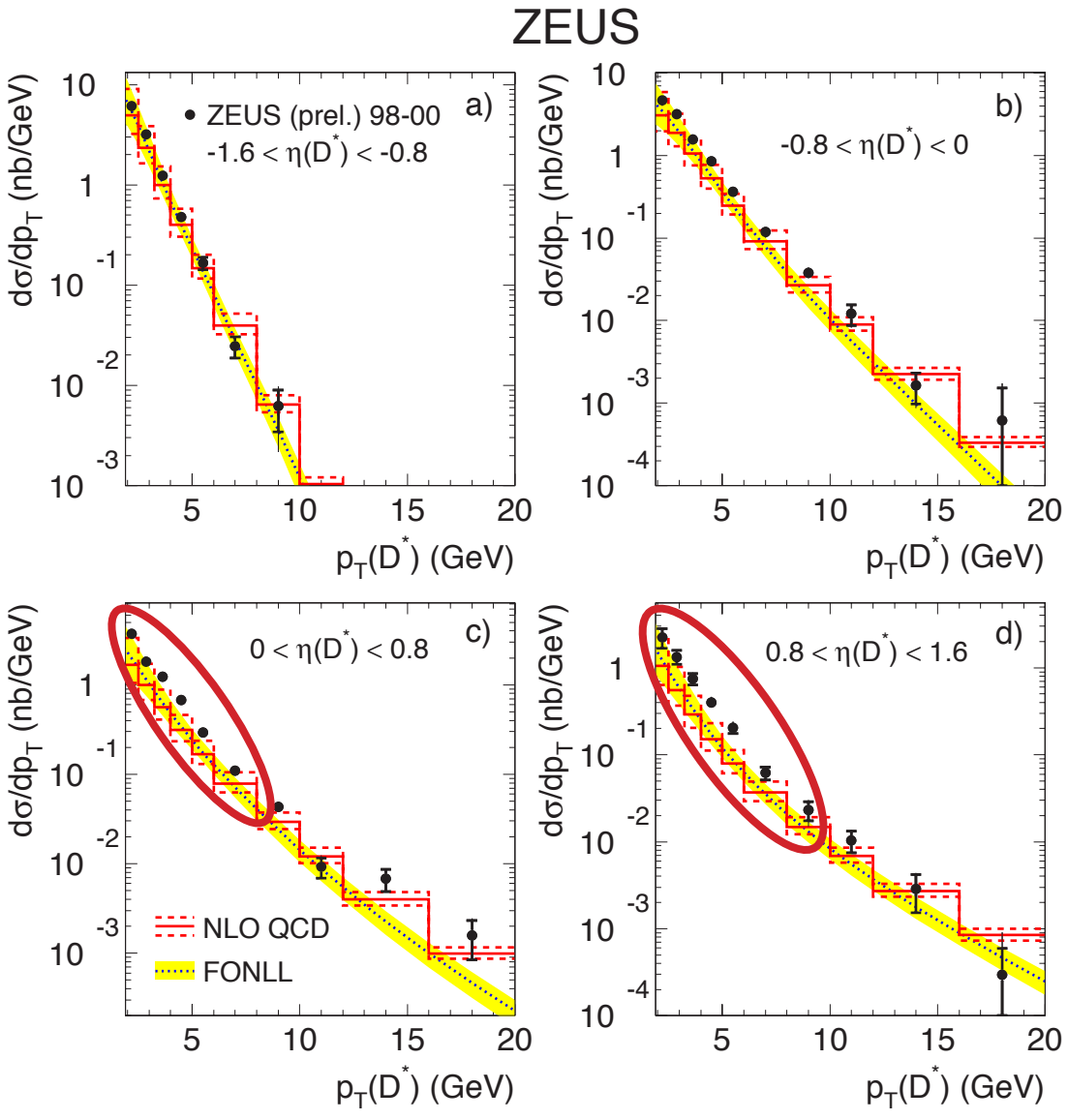
- reasonable agreement of theory with data
- sometimes data tends to be higher than prediction

Outlook:

- HERA II: much more luminosity is coming
- many more analysis to come!
- hoping for more precise calculations

Backup Slides

D^* in γp: p_t in η Bins



- in backward direction data described by both theoretical approaches
- in forward direction at low p_t data is higher than calculations

Bjorken x limits

Production rates at HERA:

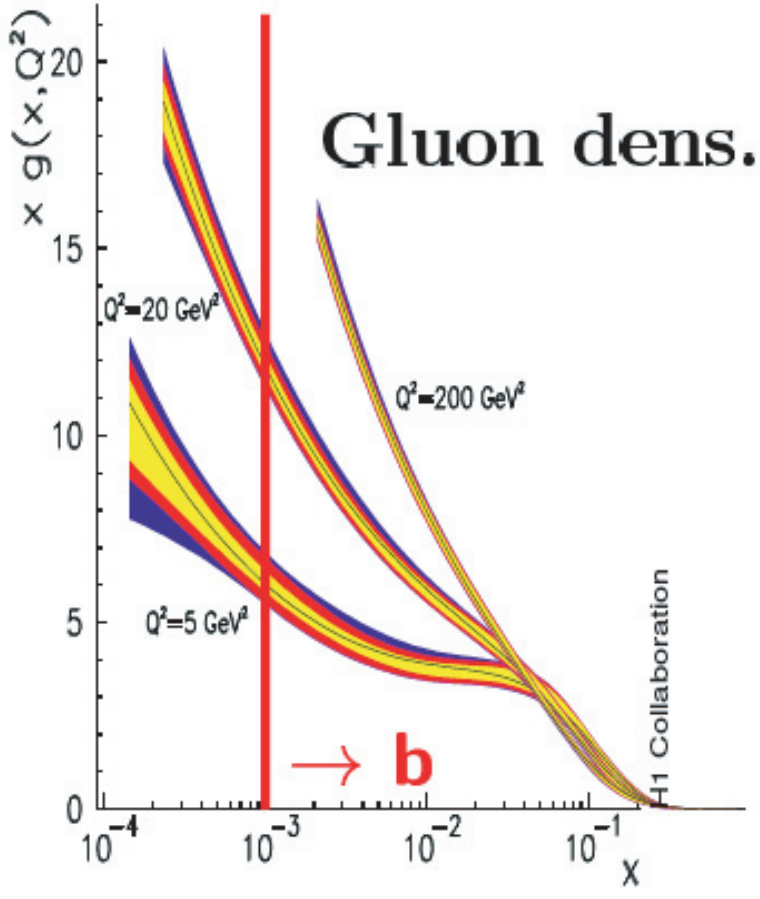
$\sigma_{uds} : \sigma_c : \sigma_b = 2000 : 200 : 1$

kin. Threshold:

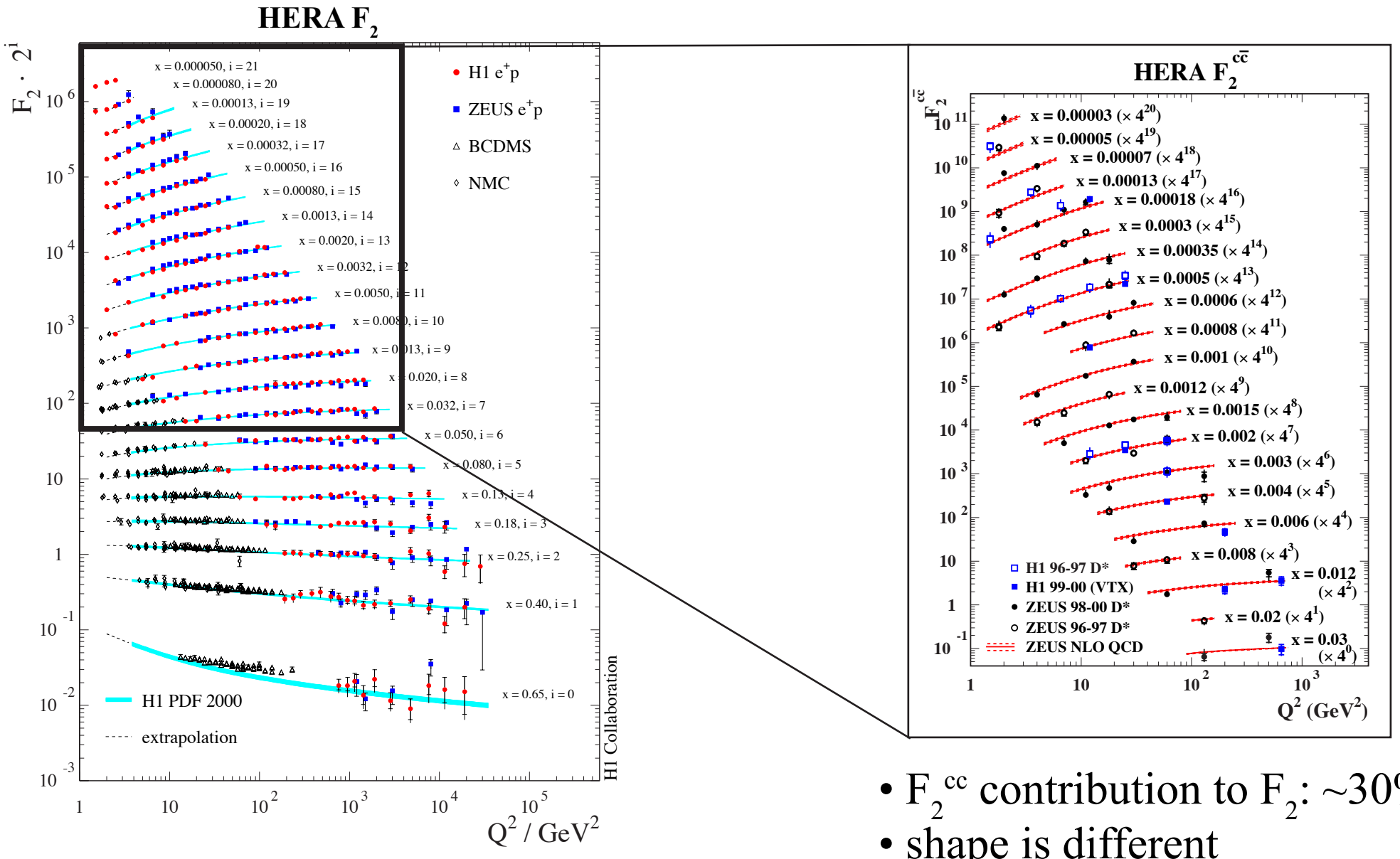
$$x_g \geqslant \frac{m_Q^2}{E_\gamma \cdot 920\ \text{GeV}}$$

charm: $x_g > 10^{-4}$

beauty: $x_g > 10^{-3}$

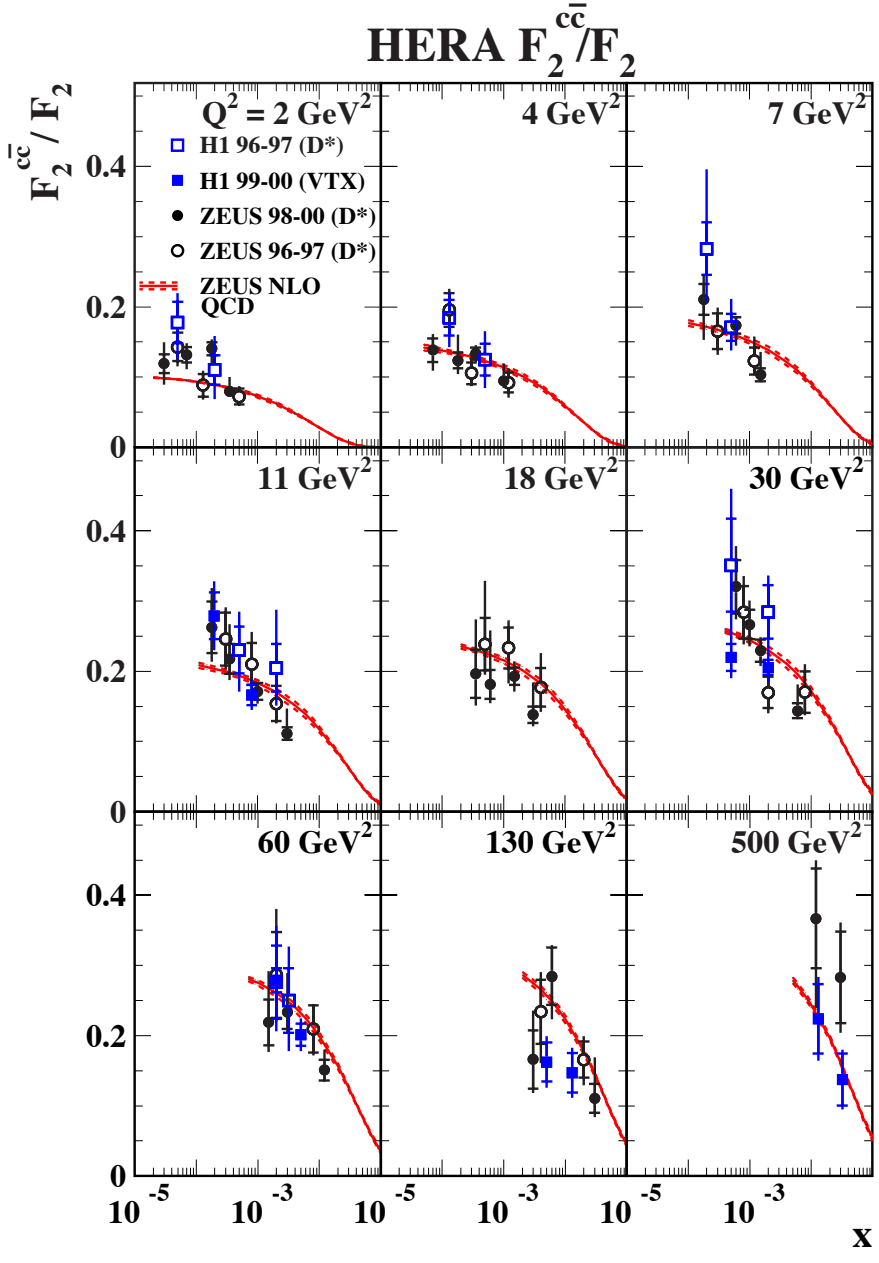


F_2 vs F_2^{cc}



- F_2^{cc} contribution to F_2: ~30%
- shape is different

F_2 vs F_2^{cc}



- F2cc contribution to F2: ~ 30%
- shape is different