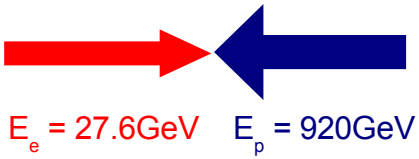
Heavy Flavours at ZEUS and H1

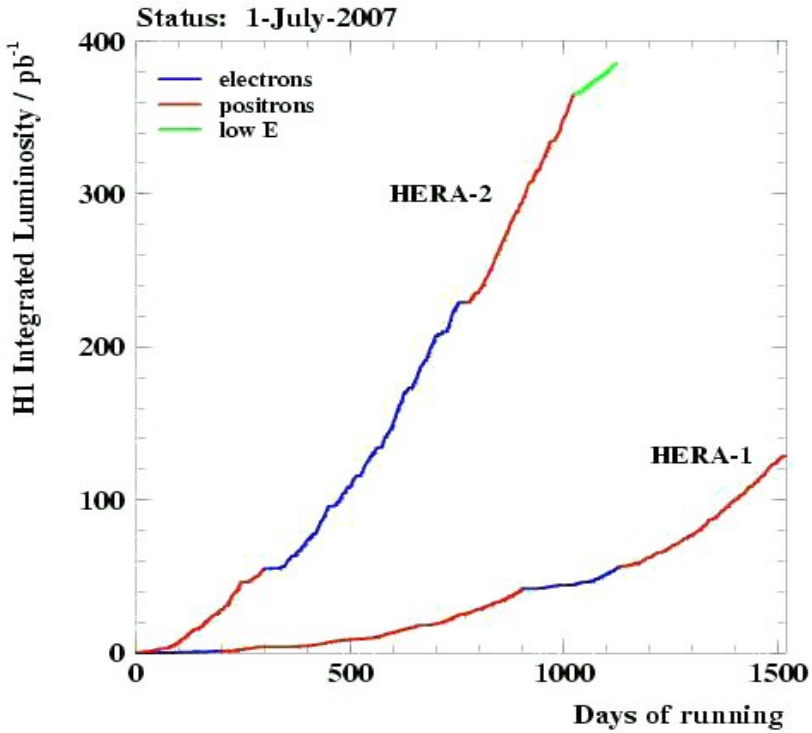
Moriond QCD and High Energy Interactions

Sarah Boutle

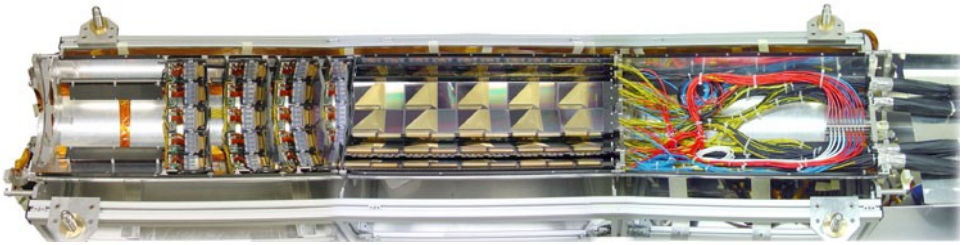
HERA



- 1992 – 2007
- Experiments gated 500 pb^{-1}
- Luminosity upgrade in 2001 → HERA II

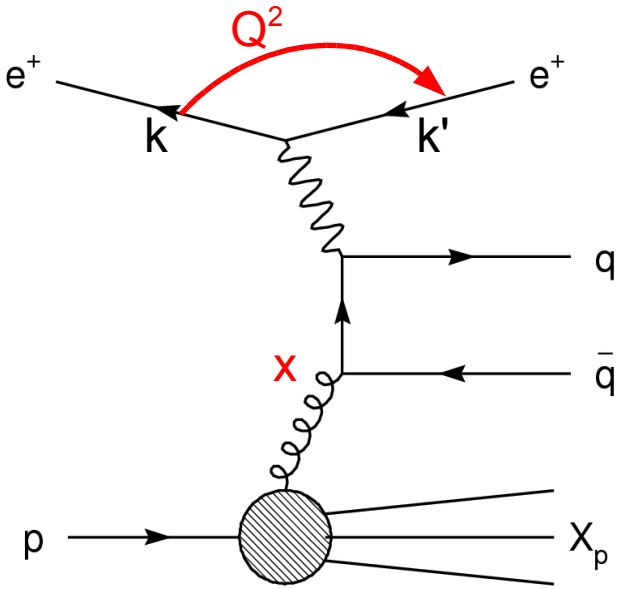


- Since HERA II both experiments equiped with Silicon Vertex Detectors
- Important for heavy flavour measurements



Heavy quark production

- Heavy quarks (b and c) predominantly by Boson-Gluon Fusion



- $Q^2 = -q^2$ (photon virtuality)
- $x = Q^2/2p.q$
- $y = k'.p/k.p$ (inelasticity)
- Kinematic regimes:
  - $Q^2 > 1\text{GeV}^2$ Deep inelastic scattering
  - $Q^2 \sim 0\text{GeV}^2$ Photoproduction

PDF

Proton and Photon structure functions
Direct sensitivity to gluon density in proton

→

Hard Scatter

Dynamics of NLO QCD
Large quark mass provide hard scale

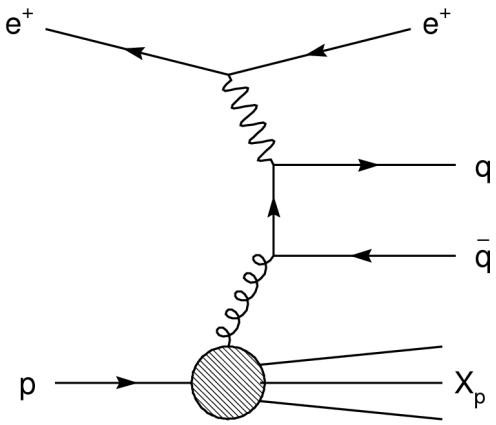
→

Fragmentation

Describes parton-hadron transition
Non-perturbative

Theoretical models

- Massive approach
  - Heavy quarks have mass and are not part of structure functions
  - c and b are produced perturbatively in the hard interaction
  - Appropriate for $Q^2 \sim M_b^2$, if $Q^2 >> M_b^2$ then large $\ln(Q^2/M_b^2)$ appear
  - FMNR (Photoproduction), HVQDIS (DIS)

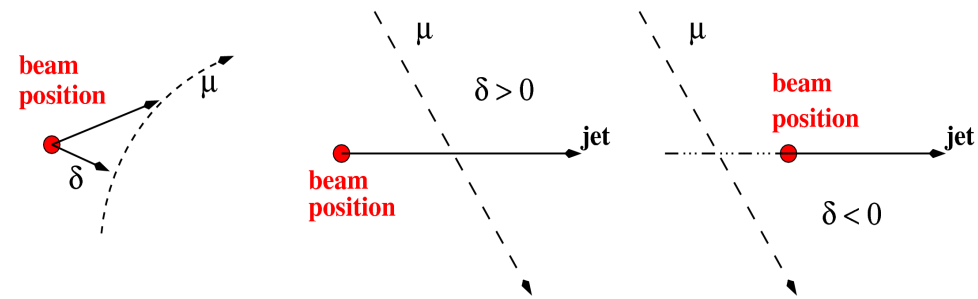


- GM-VFNS (General Mass Variable Flavour Number Scheme)
  - Heavy quarks are treated as massless at high Q^2, p_T^2
  - And massive at low Q^2, p_T^2

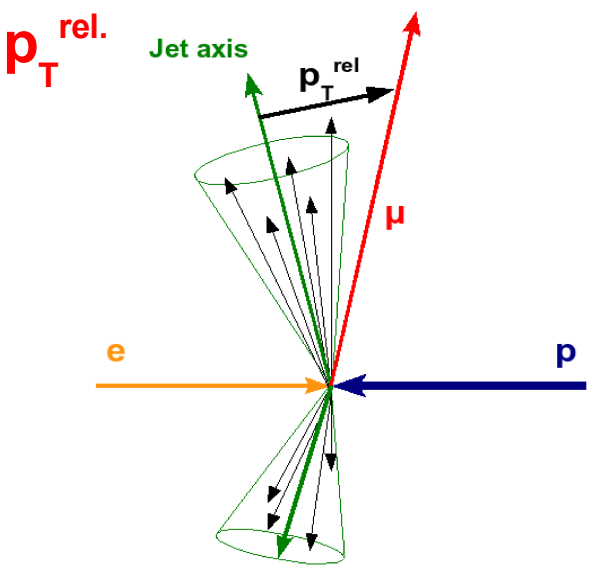
Beauty in photoproduction

- Recent measurements: semi-leptonic decay into muons
- Properties of the b-quark:
  - Large mass $m_b \sim 5$GeV → Larger $p_T^{rel.}$
  - Long lifetime → Larger positive δ

impact parameter, δ

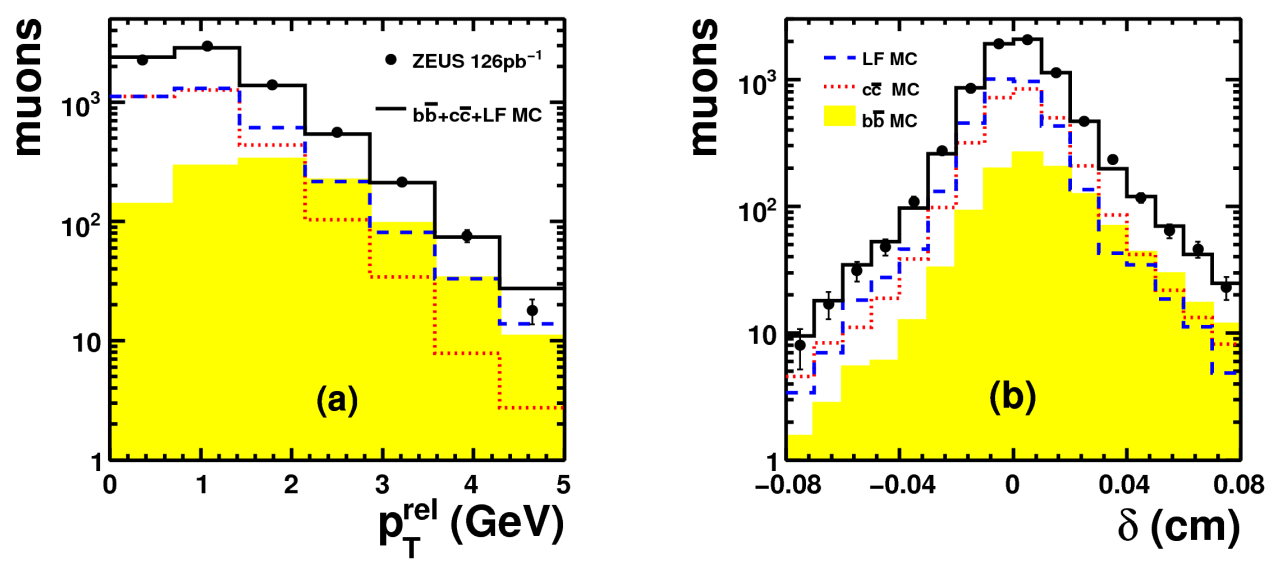


Discriminates b and c from background

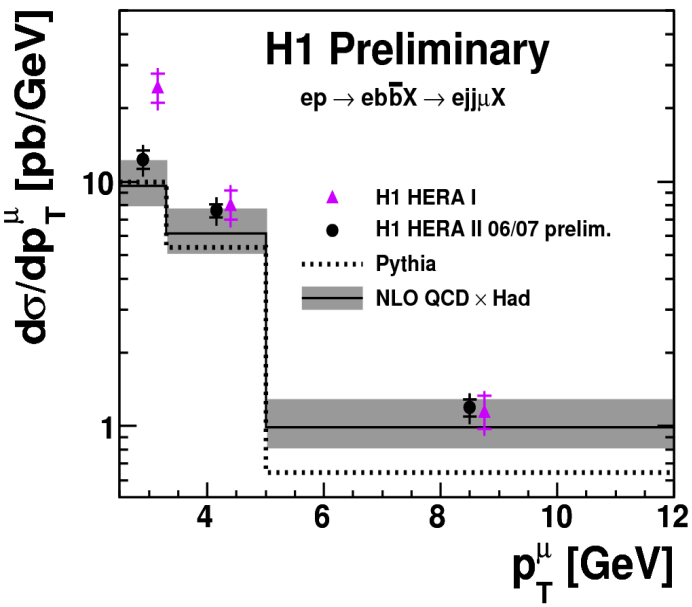


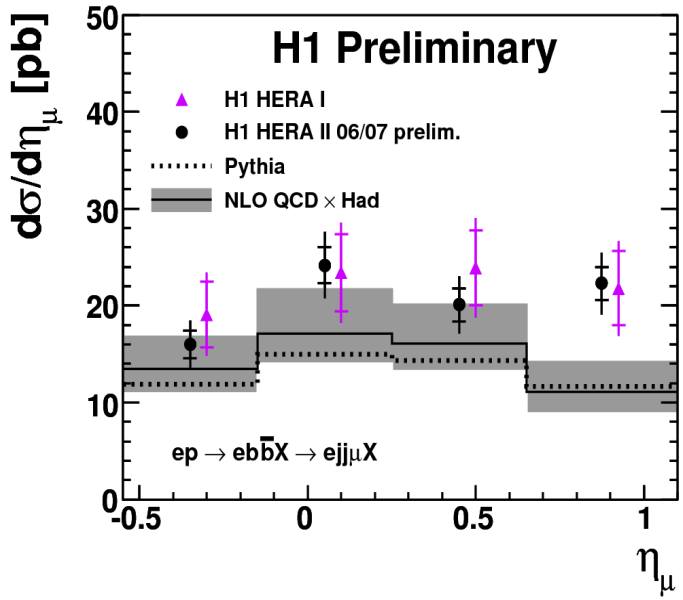
Discriminates b from background

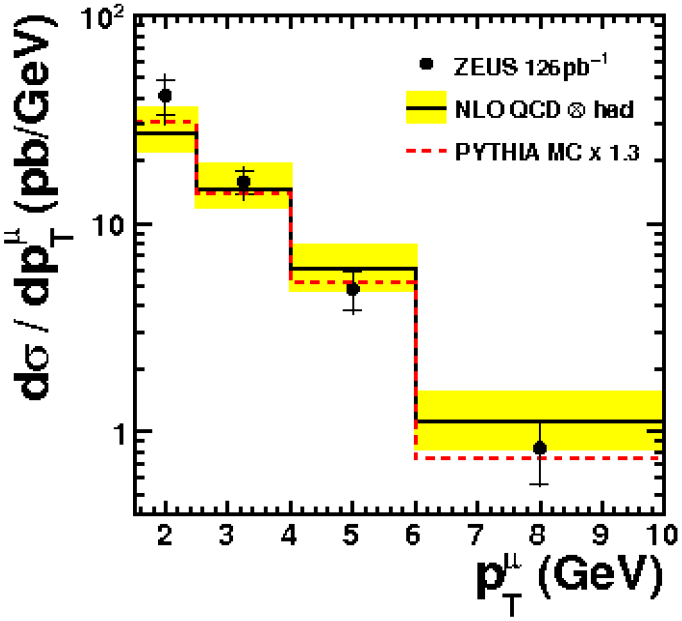
ZEUS

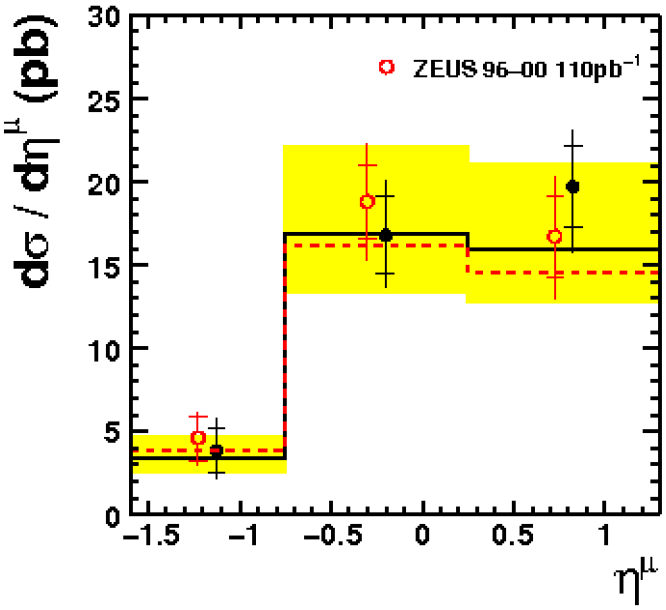


Beauty in photoproduction



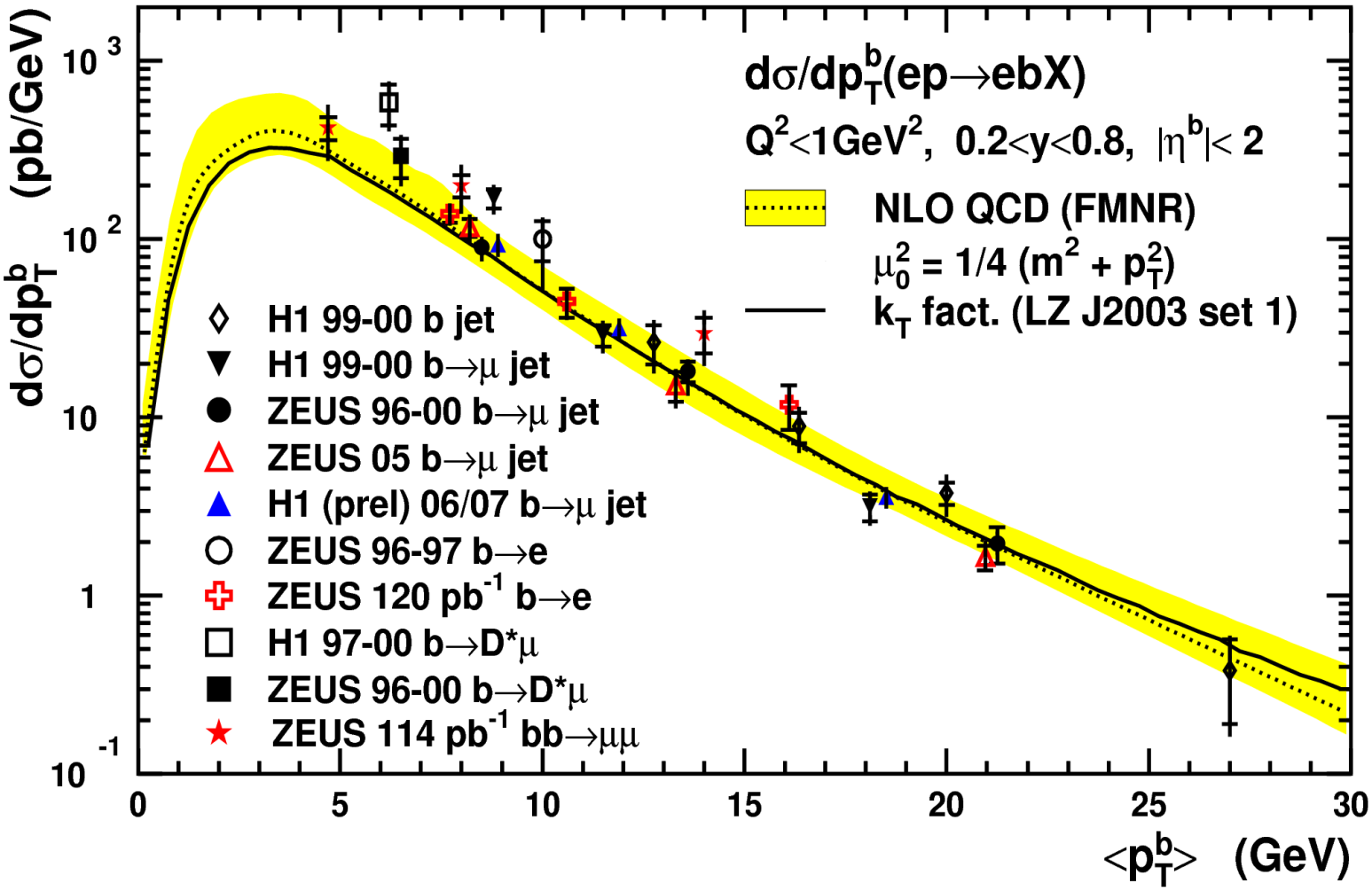




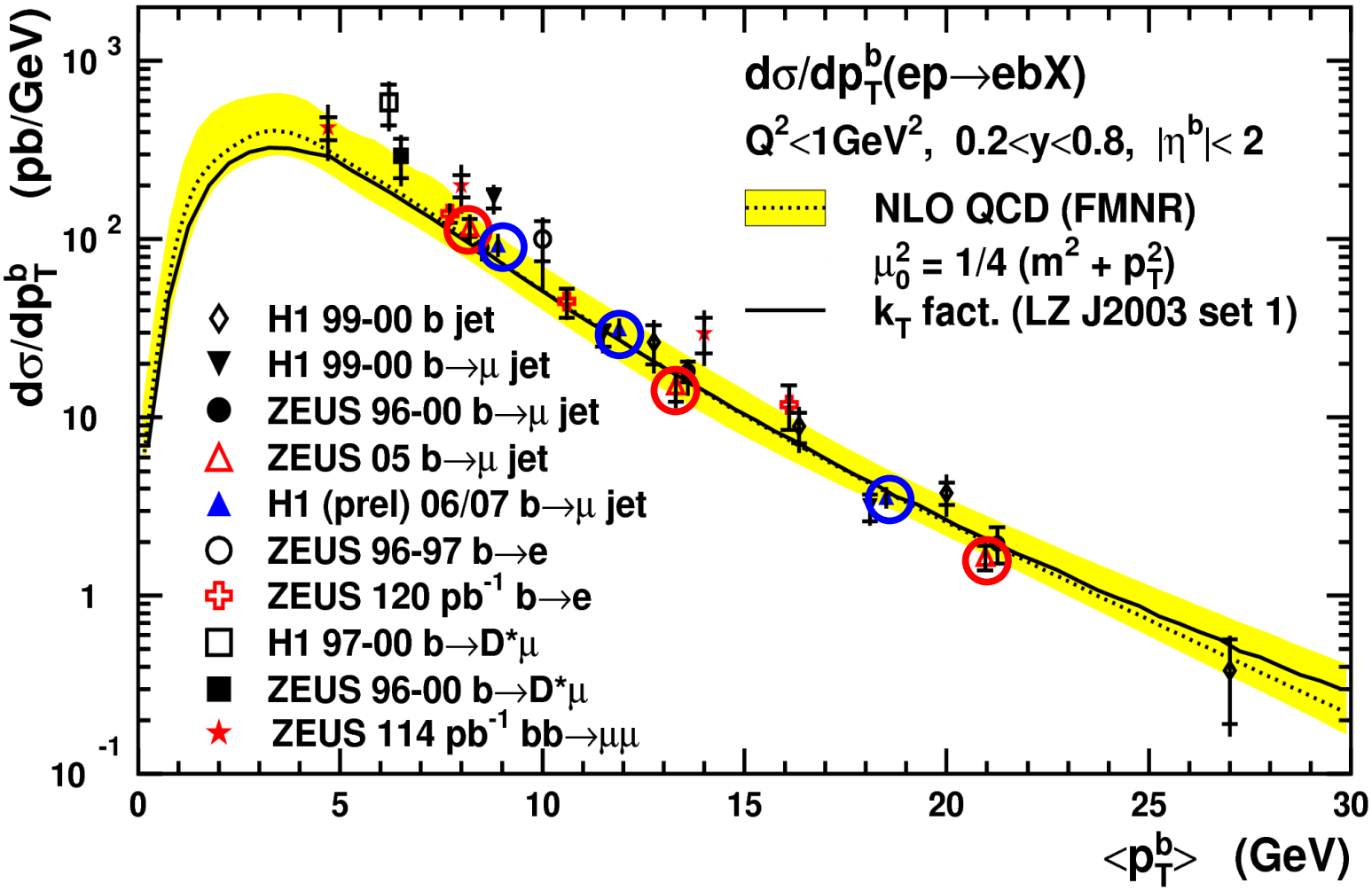


- Recent results give good agreement with NLO (FMNR)
- Results are compared with HERA I measurements
- ZEUS result probes lower p_T^{μ} range
- A good test of QCD

HERA


dσ/dp$_T^b$(ep→ebX)
Q^2<1GeV^2, 0.2<y<0.8, |η^b|< 2
NLO QCD (FMNR)
μ$_0^2$ = 1/4 (m^2 + p$_T^2$)
k$_T$ fact. (LZ J2003 set 1)
H1 99-00 b jet
H1 99-00 b→μ jet
ZEUS 96-00 b→μ jet
ZEUS 05 b→μ jet
H1 (prel) 06/07 b→μ jet
ZEUS 96-97 b→e
ZEUS 120 pb^{-1} b→e
H1 97-00 b→D*μ
ZEUS 96-00 b→D*μ
ZEUS 114 pb^{-1} bb→μμ
dσ/dp$_T^b$ (pb/GeV)
<p$_T^b$> (GeV)

HERA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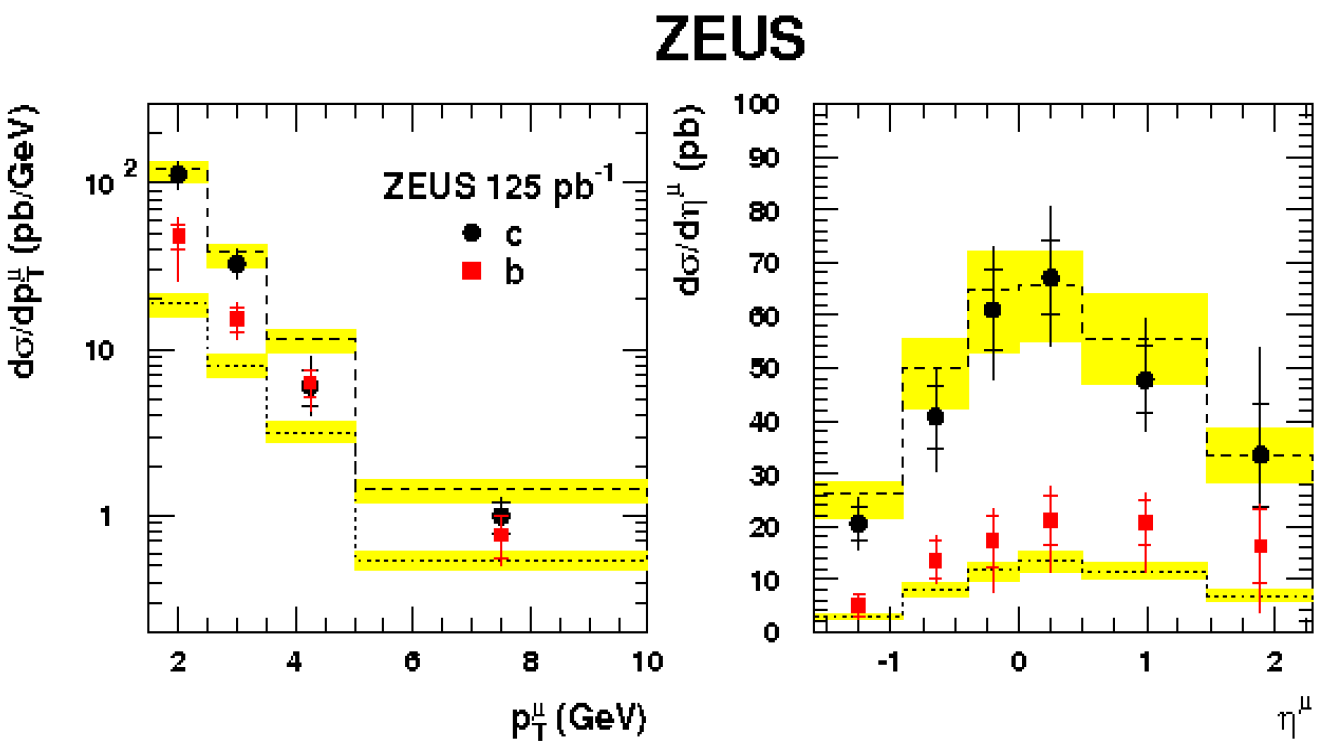
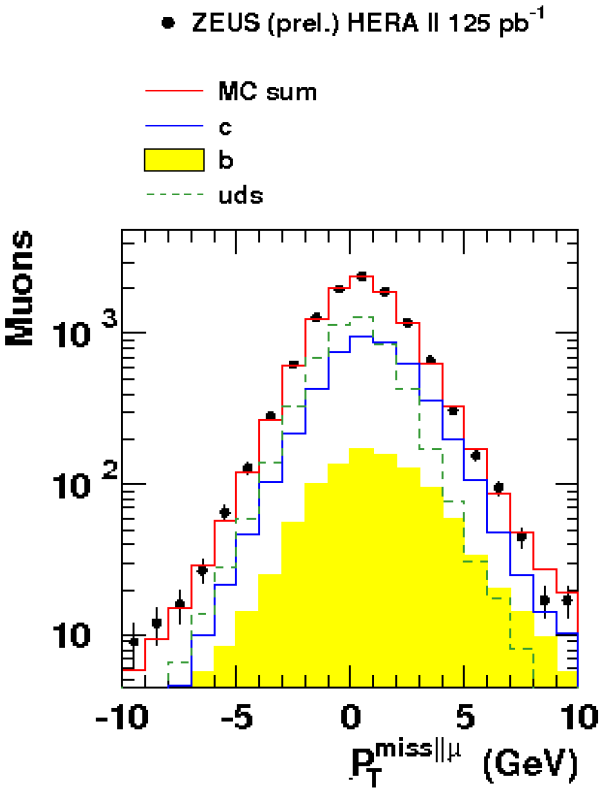
ZEUS 96-00 b→D*μ
ZEUS 114 pb^{-1} bb→μμ
dσ/dp$_T^b$ (pb/GeV)
<p$_T^b$> (GeV)

Beauty and charm in DIS

- Identify b and c in DIS via semi-leptonic decay into muons
- Discriminating variables:
  - $p_T^{rel.}$
  - δ
  - $p_T^{miss \parallel \mu}$, missing transverse momentum parallel to muon direction

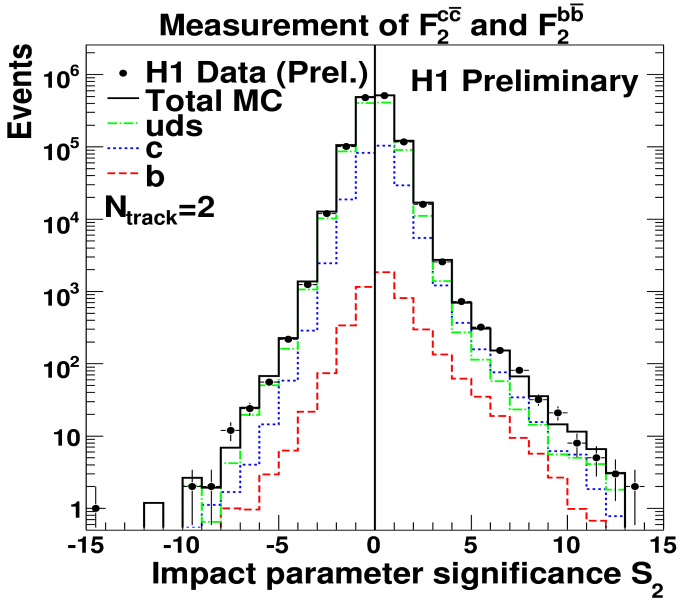


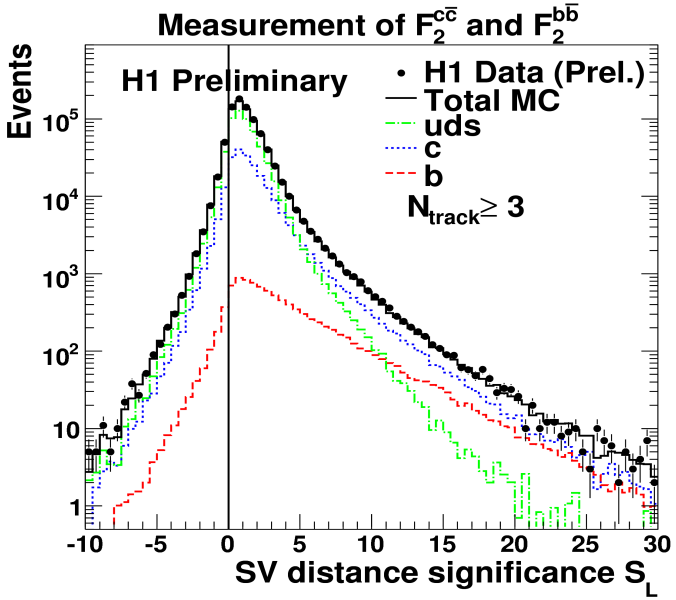


- Charm cross sections are well described by NLO (HVQDIS)
- Tendency for b cross sections to lie above theory at low p_T^{μ}

Inclusive track measurement

- Inclusive method: using all tracks (p_T > 0.5GeV) detected by Silicon Vertex detector
- Allows separation of b,c and lighter quarks
- c and b fractions extracted using signed impact parameter significance $\delta / \sigma(\delta)$
- Also uses the reconstructed position of a secondary vertex: significance $L_{xy} / \sigma(L_{xy})$
- This gives better discrimination between b and c quarks

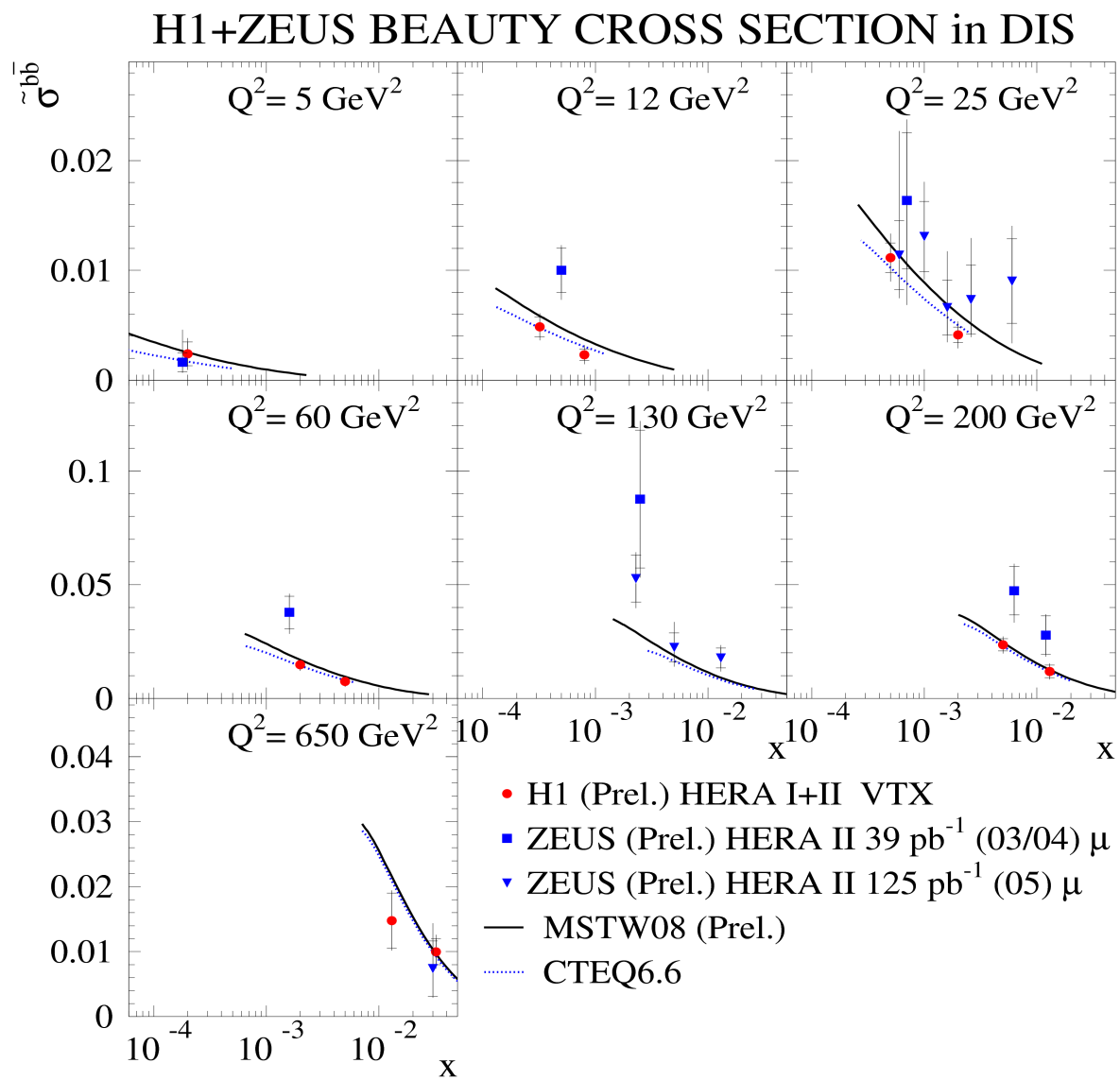




Measurements of F_2^{bb}

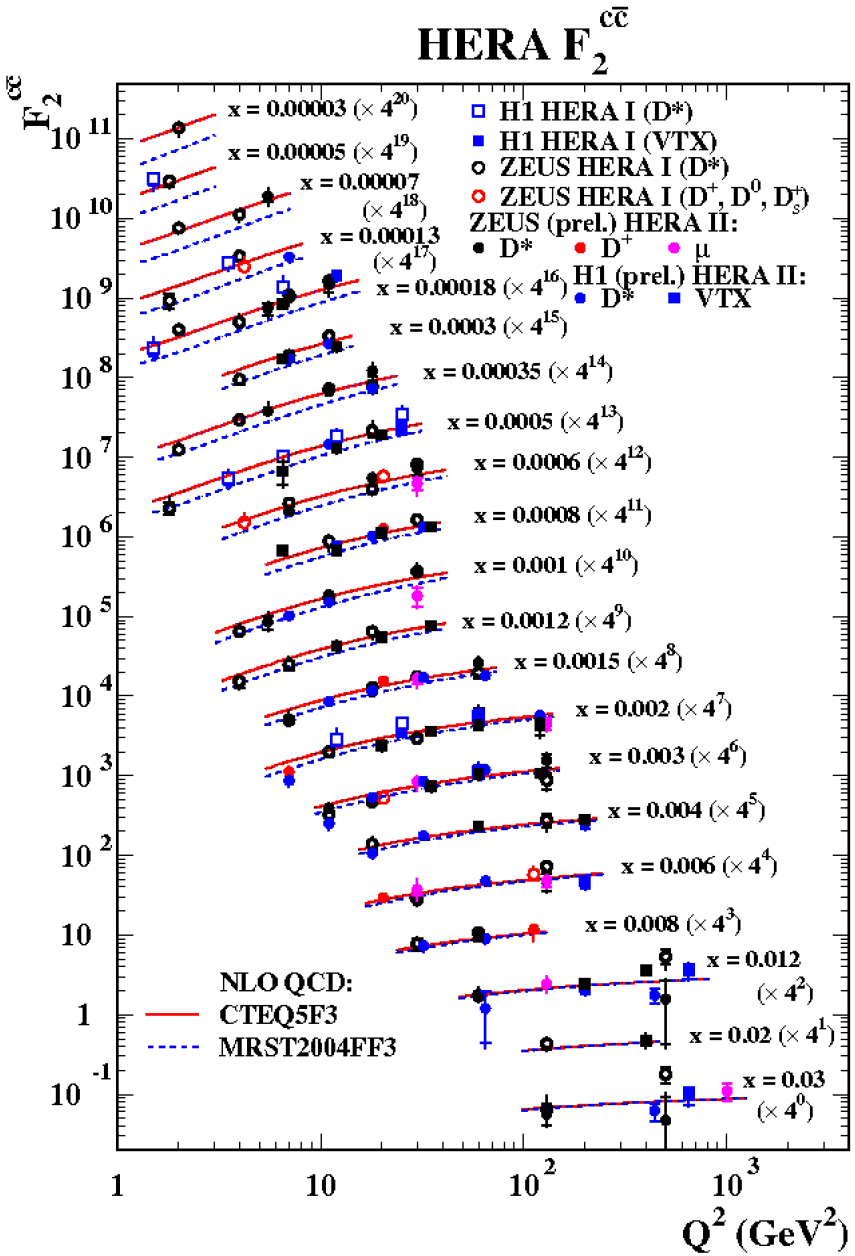
$$\frac{d^2\sigma^{q\bar{q}}}{dx\,dQ^2} = \mathcal{K}\left[F_2^{q\bar{q}}(x,Q^2) - \frac{y^2}{Y_+}F_L^{q\bar{q}}(x,Q^2)\right] = \mathcal{K}\,\tilde{\sigma}^{q\bar{q}}(x,Q^2,s)$$

- Probing the structure of the proton
- Reasonable agreement between different datasets
- Compared with NLO predictions (GM-VFNS)
- Limited by statistics
- Not possible to distinguish between PDFs



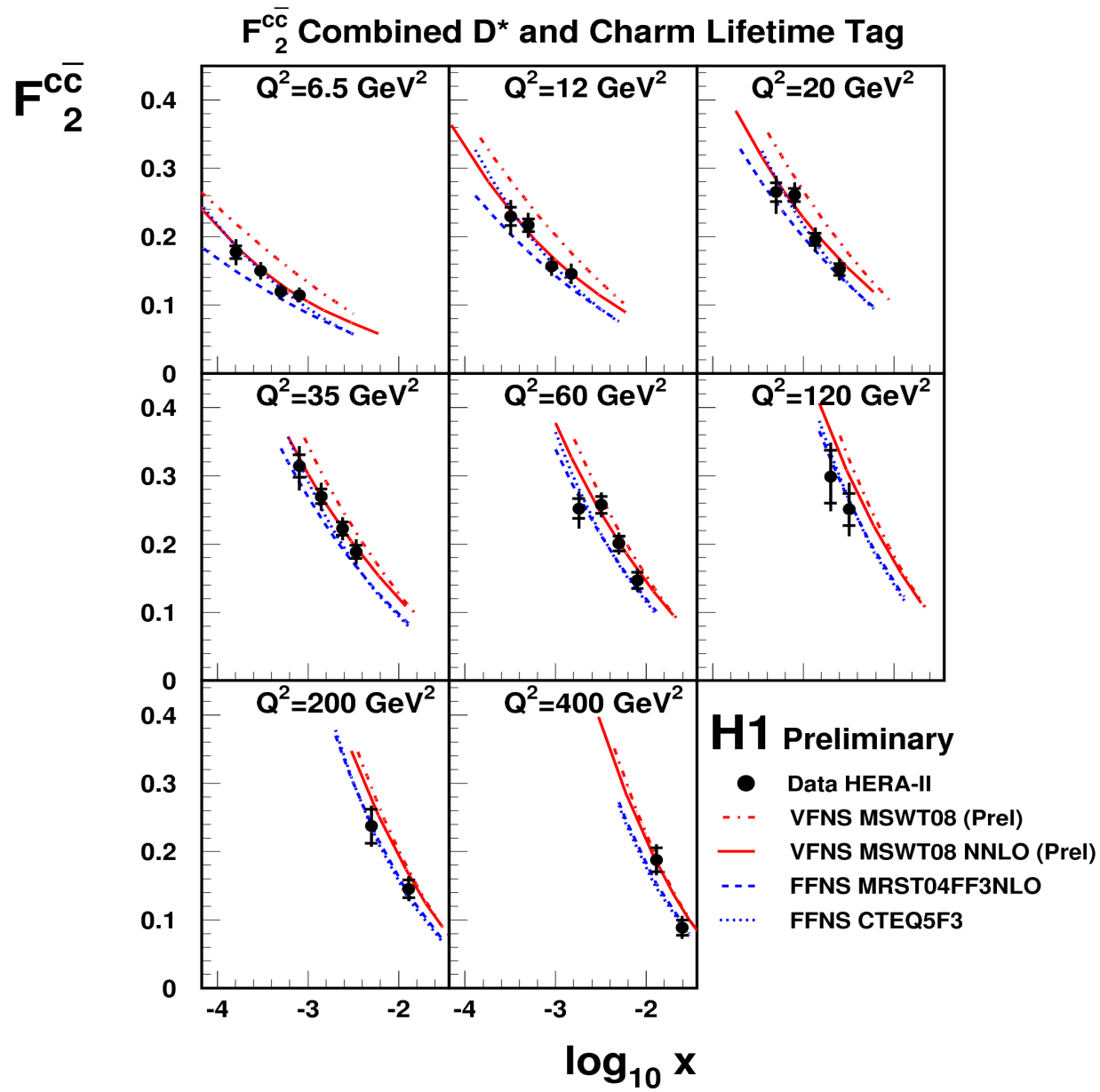
Measurements of F_2^{cc}

- Includes the most recent results
- Good agreement between different datasets and techniques – including D* measurements
- Reasonable agreement with NLO predictions (FFNS)
- High enough precision that we can distinguish between PDFs



Measurements of F_2^{cc}

- H1 have combined D* and lifetime measurements
- Combination of 2 high-statistics measurements using different techniques
- Compared to different theoretical predictions



D* Meson cross section in Photoproduction

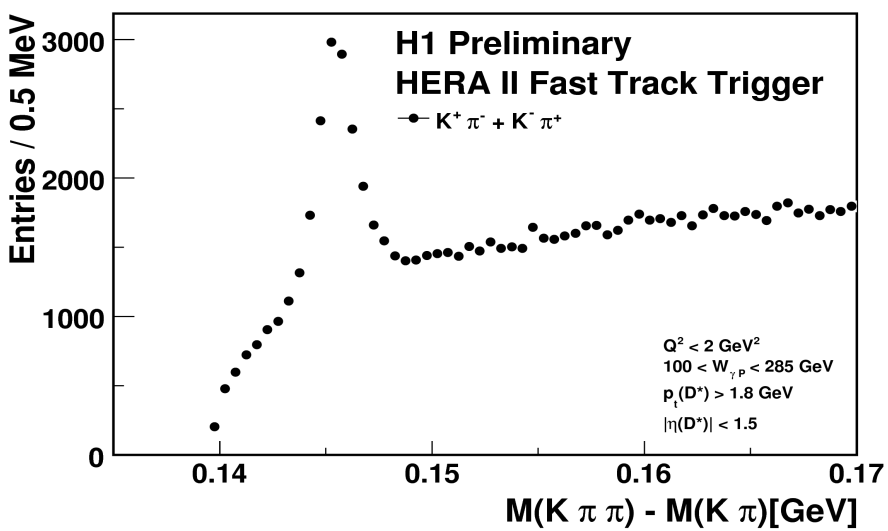
- D* meson identification in golden channel:

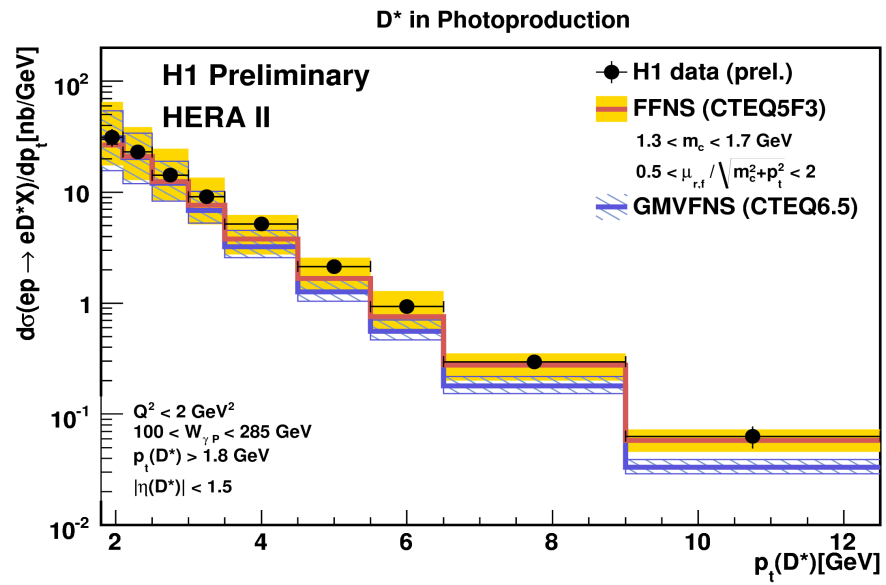
$$D^{*\pm} \rightarrow D^0\pi^{\pm}_s \rightarrow K\ \pi^{\pm}\pi^{\pm}_s$$

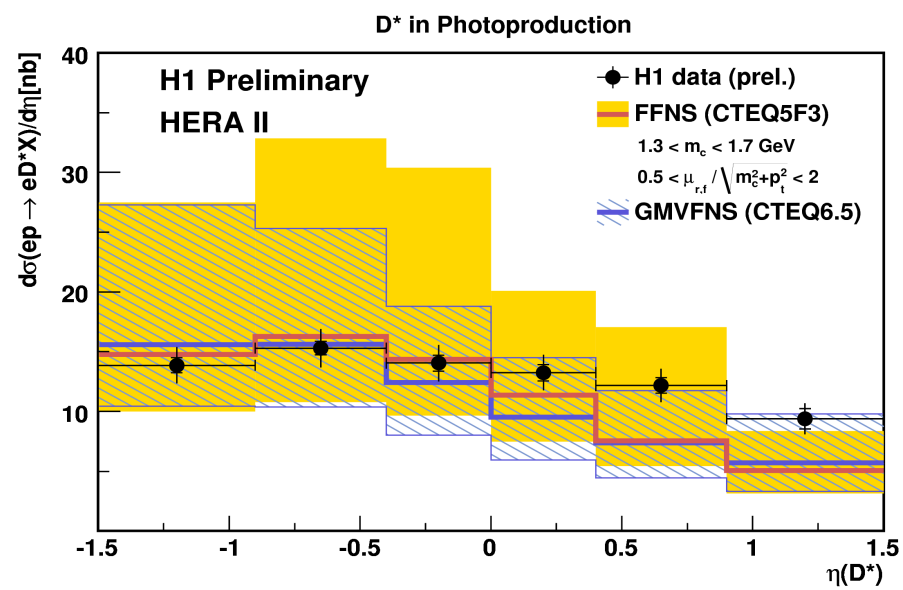
- Extract the signal using:

$$\Delta M = M(K\pi\pi_{slow}) - M(K\pi)$$

- Compare cross sections to NLO calculations
- $\eta(D^*)$ shape not well described
- Large theoretical uncertainties
- Higher order calculation needed to reduce uncertainties

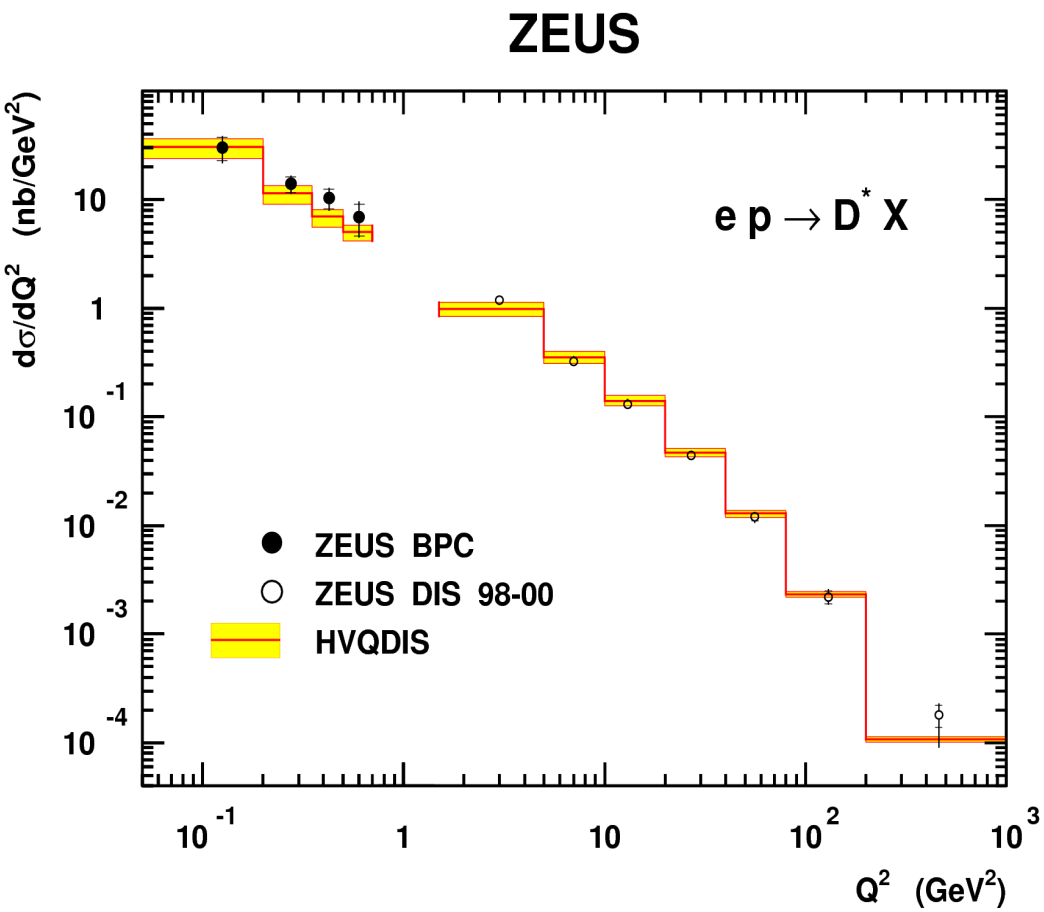


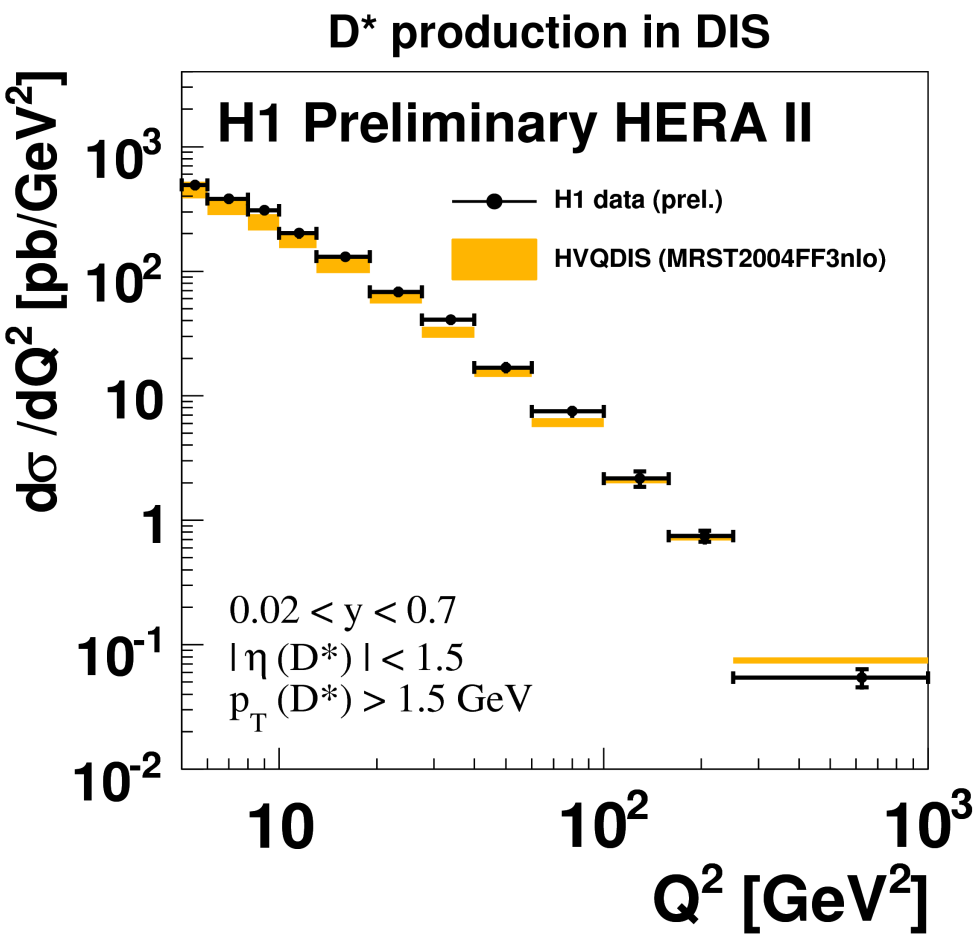




D* Meson cross section in DIS

- Data compared to massive NLO predictions (HVQDIS)
- ZEUS: measured to very low Q^2 and data described by theory
- H1: very precise measurement in Q^2 range using full HERA II statistics ~350pb^{-1}

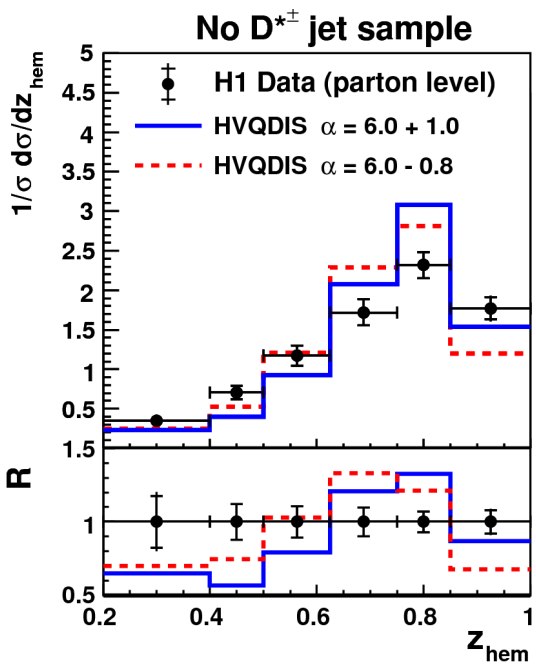




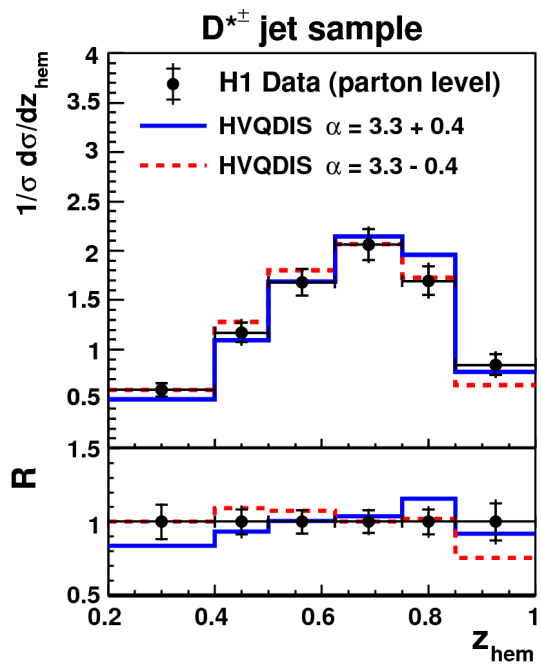
Charm fragmentation

- Fraction of c quark energy carried by D*: $z = E^{D^*} / E^c$
- In e^+e^- machines $z \sim E^{D^*} / E^{beam}$
- In ep, approximate charm quark by:

  - Jet containing the D*
  - D* hemisphere method

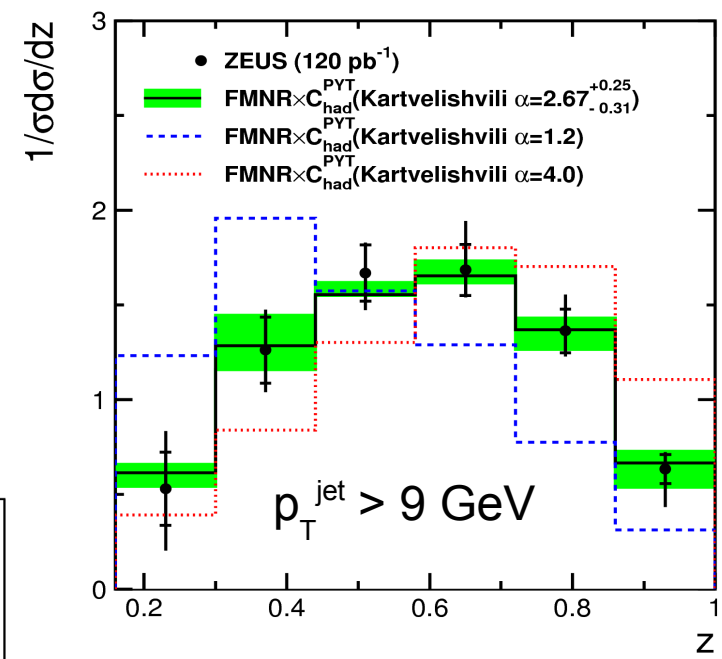


Close to threshold



$E_T^{jet} > 3$ GeV

ZEUS

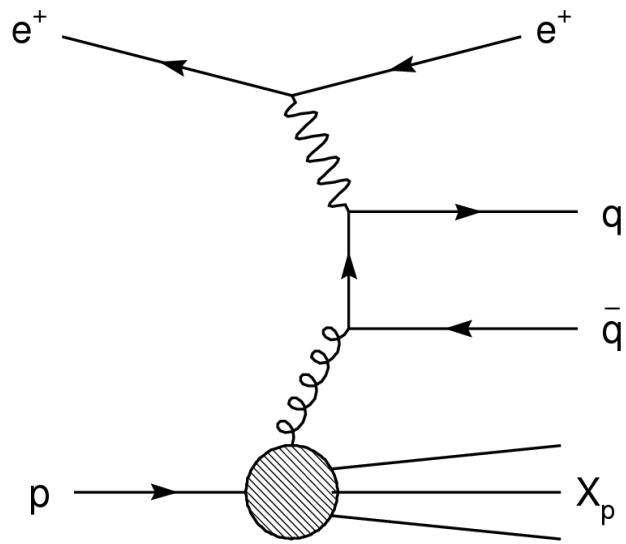


- Kartvelishvili:

$$D_c^{D^*}(z) \propto z^{\alpha}(1-z)$$

- No jet sample needs harder fragmentation than D*-jet sample
- Shows inadequacy of NLO calculation to provide consistent description down to kinematic threshold

Conclusions



PDFs

Measurements of F_2^{cc} and F_2^{bb} .

Good agreement using different techniques and data sets.

Can distinguish between theoretical models.

Hard Scatter

Measurements of b and c cross sections.

Good test of pQCD.

Variety of techniques used.

Mostly well described by theory.

Fragmentation

Describes parton-hadron transition.

Studies of fragmentation functions carried out.

Open issues when D* is produced close to threshold.