Heavy Quark production at HERA

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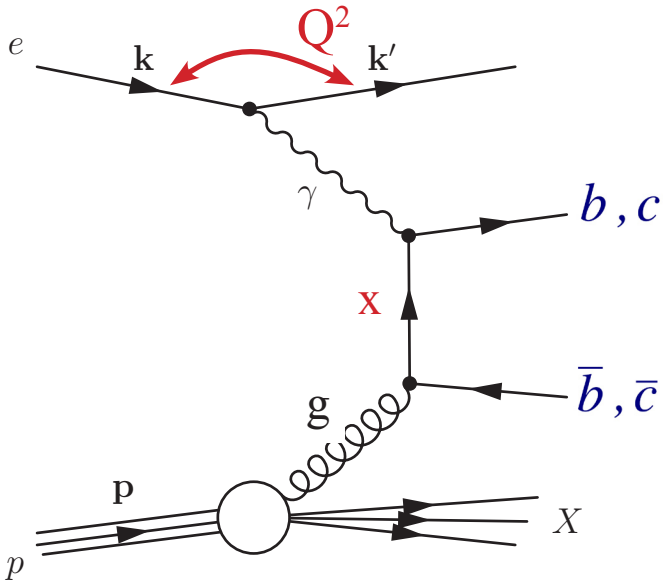
- Introduction
- Fragmentation
- Open charm/beauty measurements and methods
- Heavy Quark Contribution to the proton
- Summary and Conclusion

Lake Louise Winter Institute 2009

Production of Heavy Quarks

predominantly via boson gluon fusion



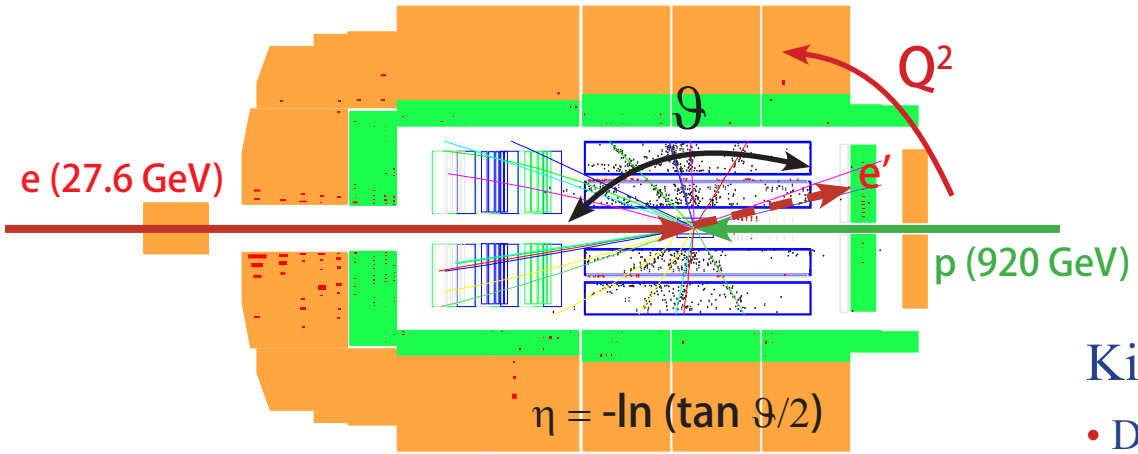
Kinematic Variables:

- squared momentum transfer:

$$Q^2 = -q^2 = -(k - k')^2$$

- Bjorken scaling variable:

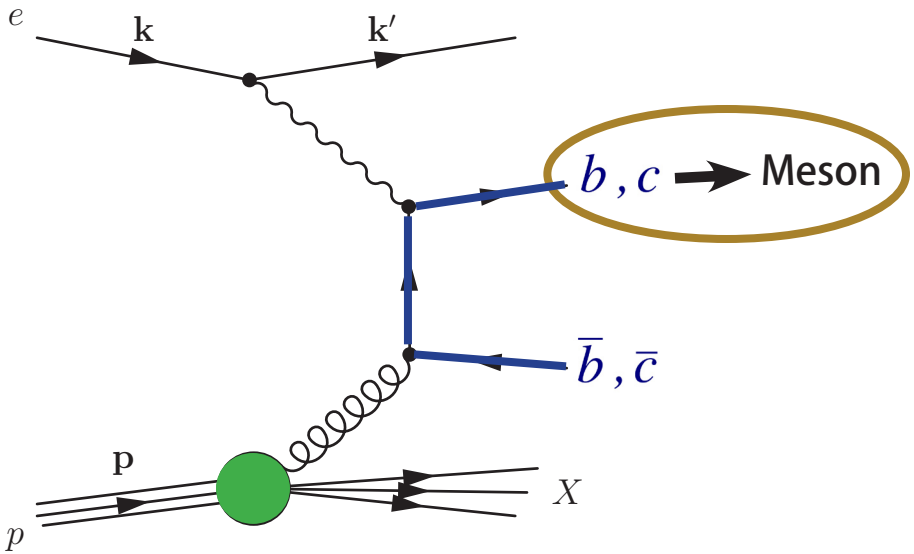
$$x = \frac{Q^2}{2Pq}$$



Kinematic regions:

- Deep Inelastic Scattering (DIS): $Q^2 \gtrsim 1$ GeV^2
- Photoproduction (γp) : $Q^2 \lesssim 1$ GeV^2

Production of Heavy Quarks



- directly sensitive to gluon density
- large mass allows perturbative calculations
- fragmentation:
  - influence on η and p_t of Mesons
  - determined experimentally

  studied variable: $z \sim E^{Meson} / E^{c,b}$

- Factorisation-Ansatz:

$$\sigma \sim f_{g/p} \otimes \hat{\sigma} \otimes D(c,b \rightarrow Meson)$$

parton density functions (non perturbative part)

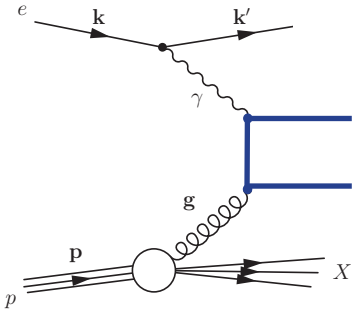
parton scattering cross section (perturbative part)

fragmentation function (non perturbative)

Predictions for Heavy Quark Production

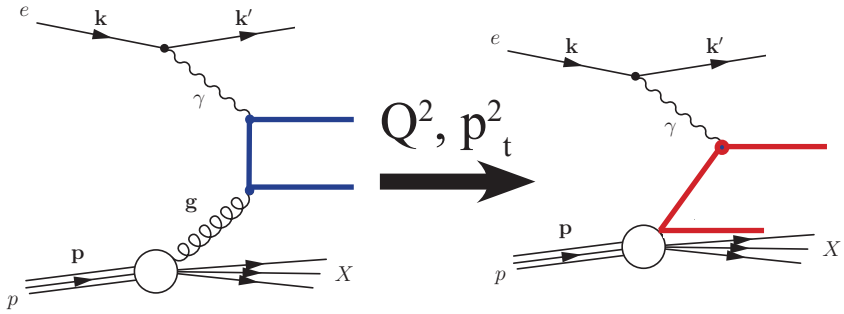
NLO programs: HVQDIS (DIS), FMNR (γp):

- FFNS (Fixed-Flavor-Number-Scheme)



- heavy quarks treated massive
- reliable at not too large Q^2, p^2_t
- independent fragmentation

- GM-VFNS (General-Mass-Variable-Flavour-Number-Scheme):



- HQ treated massless at high Q^2, p^2_t
- HQ treated massive at small Q^2, p^2_t
- reliable at small and high scales

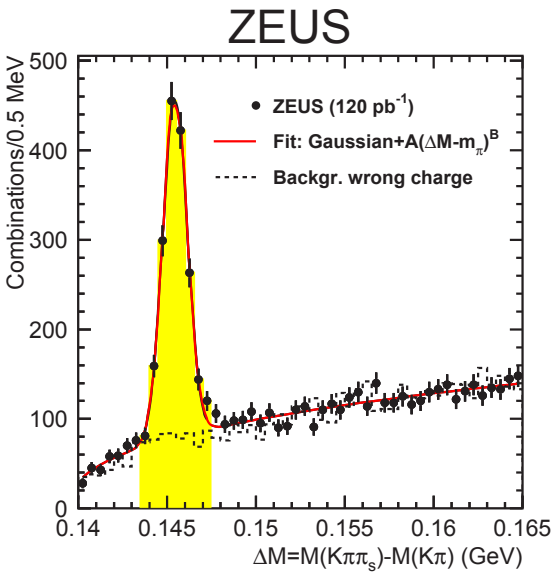
Charm Fragmentation

$z \sim E^{D^*} / E^c$

D* Meson identification via Golden Decay Chanel: $D^{*\pm} \rightarrow D^0 \pi_s^{\pm} \rightarrow K^{\mp}\pi^{\pm}\pi_s^{\pm}$

- ΔM-method used to extract signal:

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

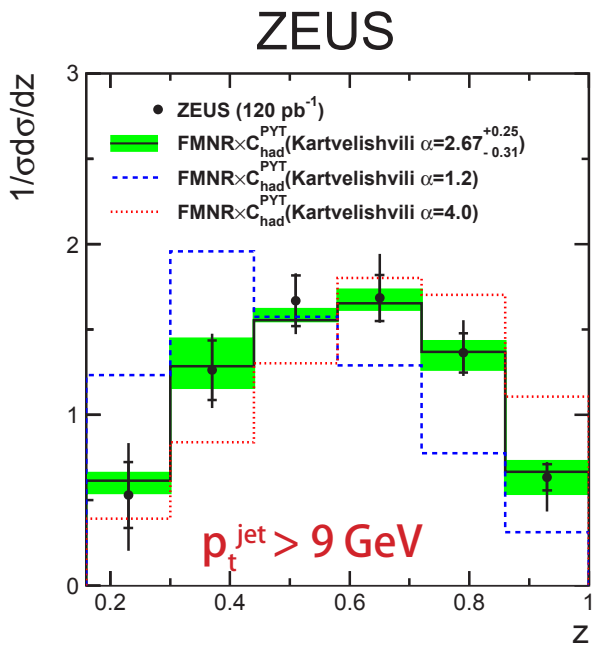


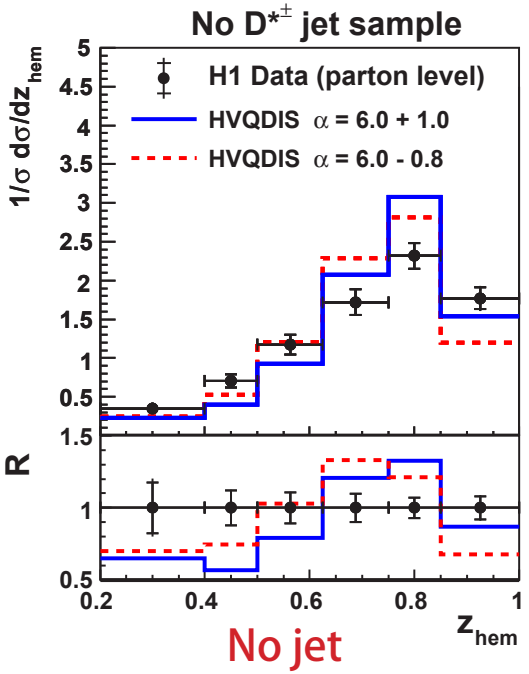
Approximate charm quark by:

- jet containing the D*
  (works far above threshold)
- D* hemisphere method
  (works also close to threshold)

Various fragmentation functions tested

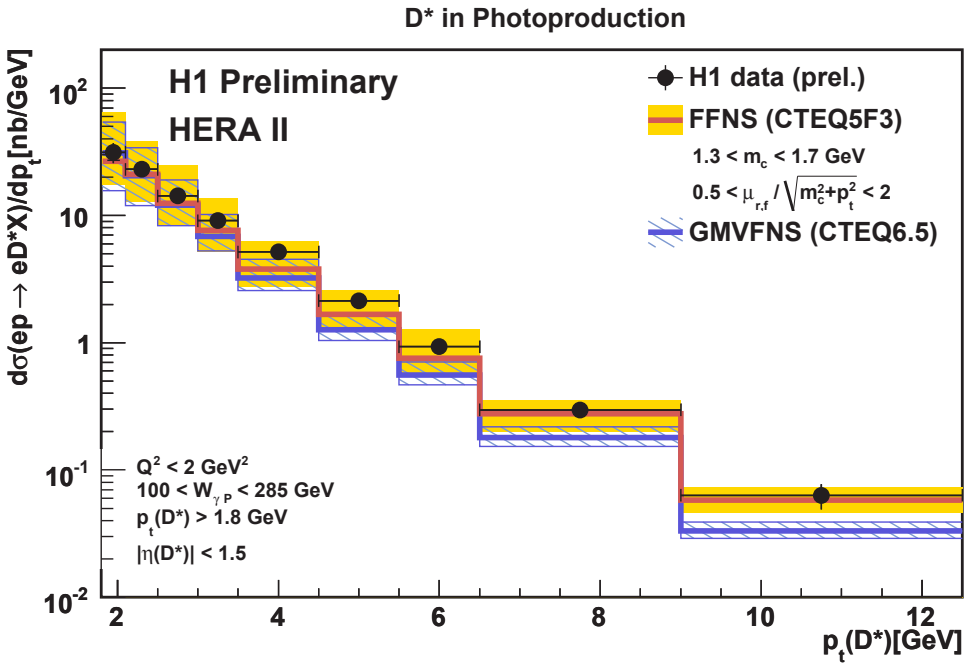
- Kartvelishvili: $D_c^{D^*}(z) \propto z^{\alpha}(1-z)$

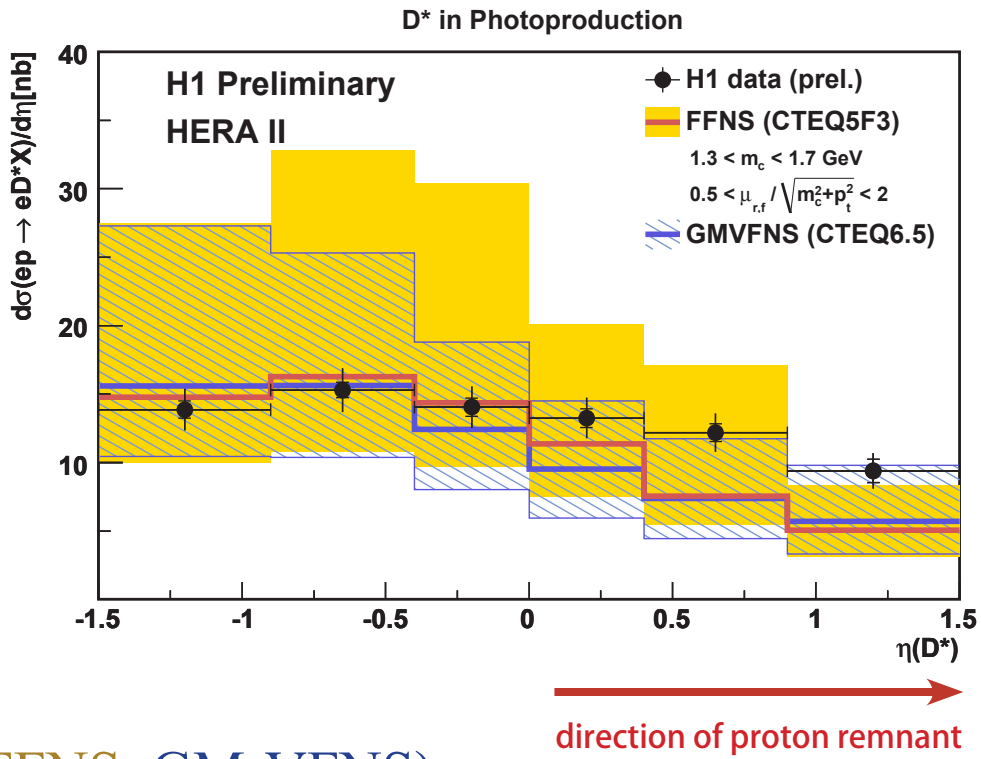




- no jet sample needs harder fragmentation
  compared to D*+Jet sample

Cross Section of D* Mesons in γp

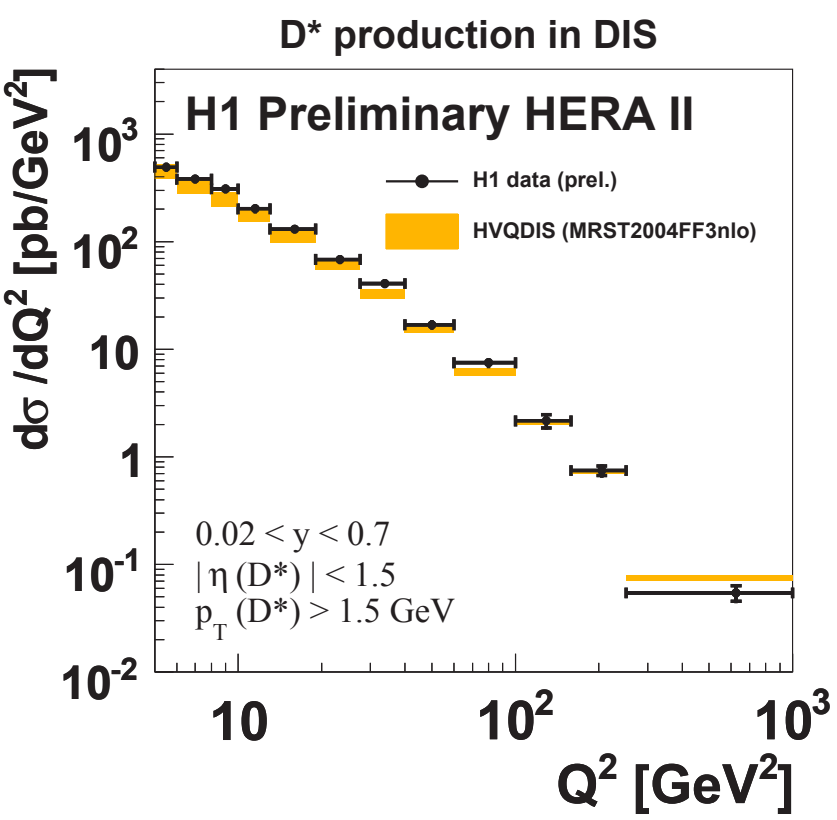


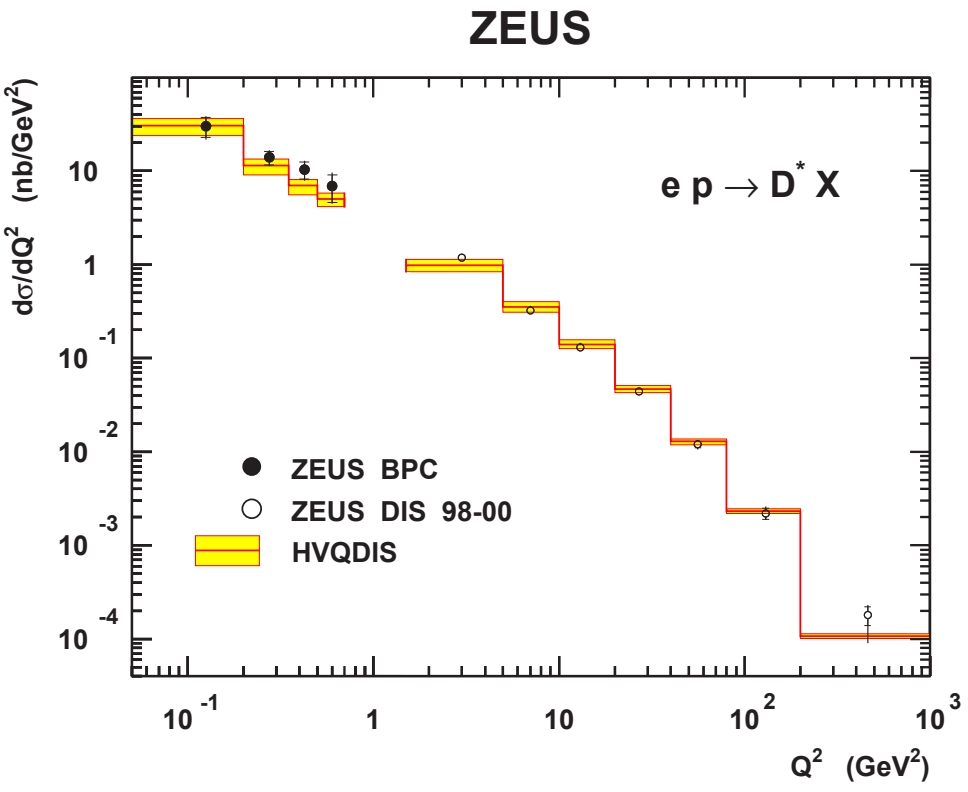


Data compared to NLO calculations: (FFNS, GM-VFNS)

- general reasonable agreement with NLO QCD within uncertainties
- η(D*) shape not well reproduced
- large theory uncertainties due to scale variations
- higher order calculation (NNLO) needed to reduce uncertainties

D* Meson Cross Section in DIS



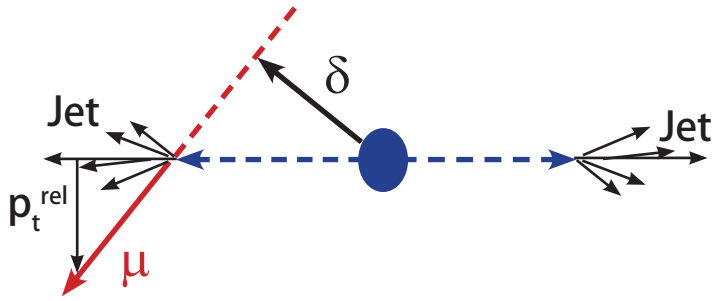


Data compared to a massive NLO calculations: (HVQDIS)

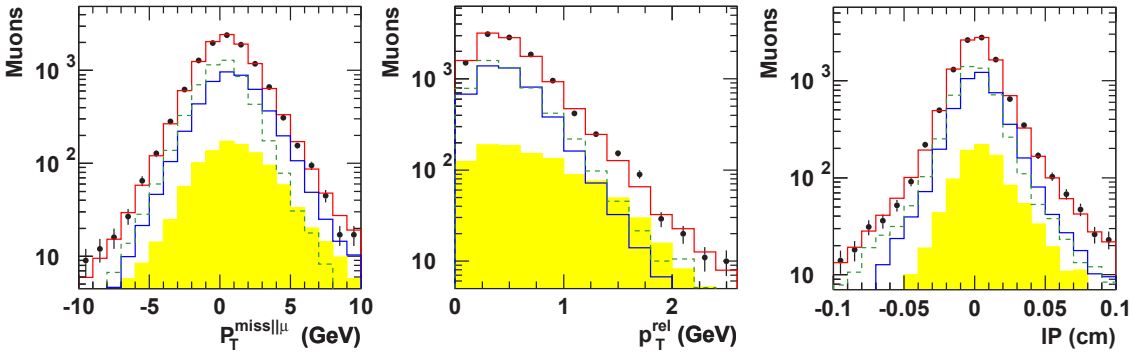
- H1: full HERA II statistic (~ 350 pb^{-1})
- ZEUS: very low Q^2 measured, data described by theory over six orders of magnitude
- data is described at high Q^2 where massive approach may not to be appropriate

Charm and Beauty Production

Measurement from semileptonic decays

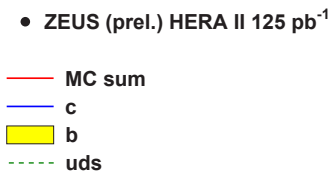


- semileptonic decays: p_t^{miss}
- transverse momentum relative to jet axis: p_t^{rel}
- impact parameter: δ (IP)

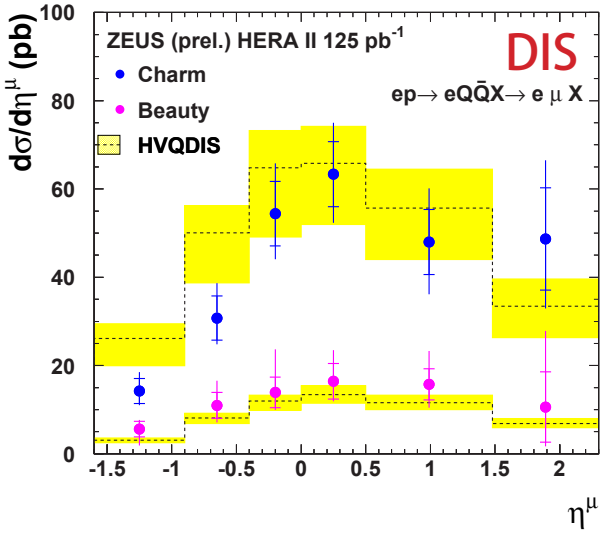


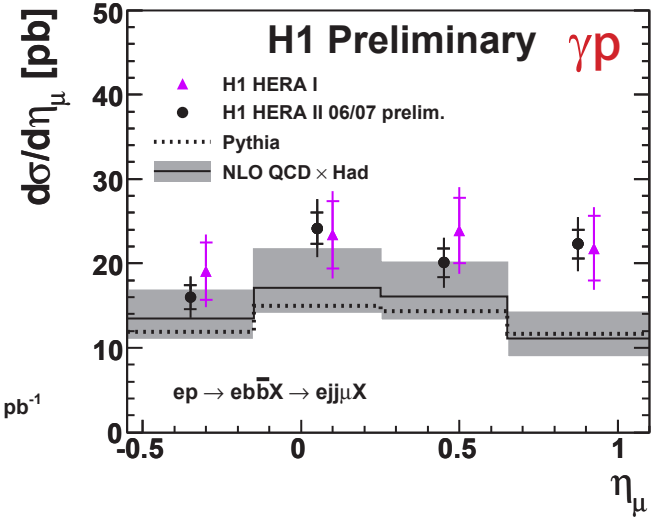
- combine the 3 methods:

  use 3D fit to decompose into charm, beauty and light flavor



ZEUS



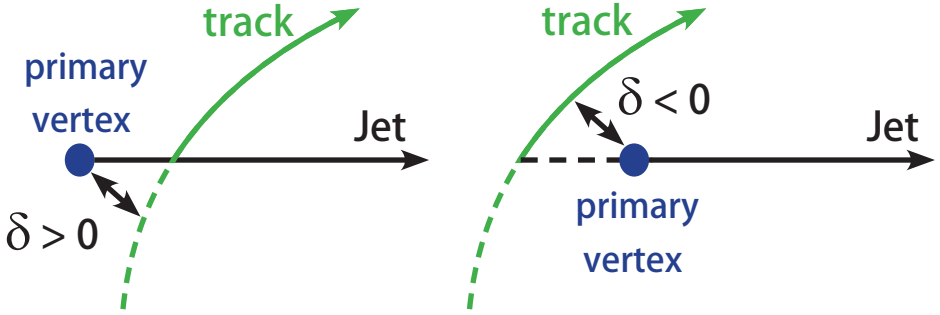


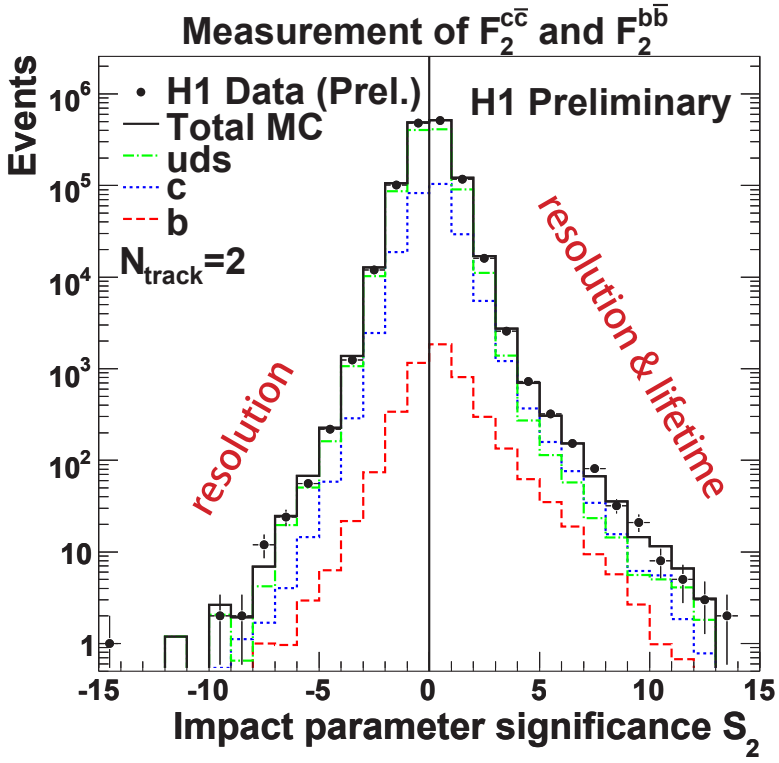
- reasonable agreement with NLO prediction

Inclusive Lifetime Analysis

Use all tracks ($p_t > 500$ MeV)
with hits in silicon vertex detector

- signed impact parameter significance: $S = \delta/\sigma(\delta)$





S_2: tracks with the second highest significane

- use significance to tag heavy flavors:
  - charm and beauty assymetric, due to long liftime
  - light flavors mostly symetric

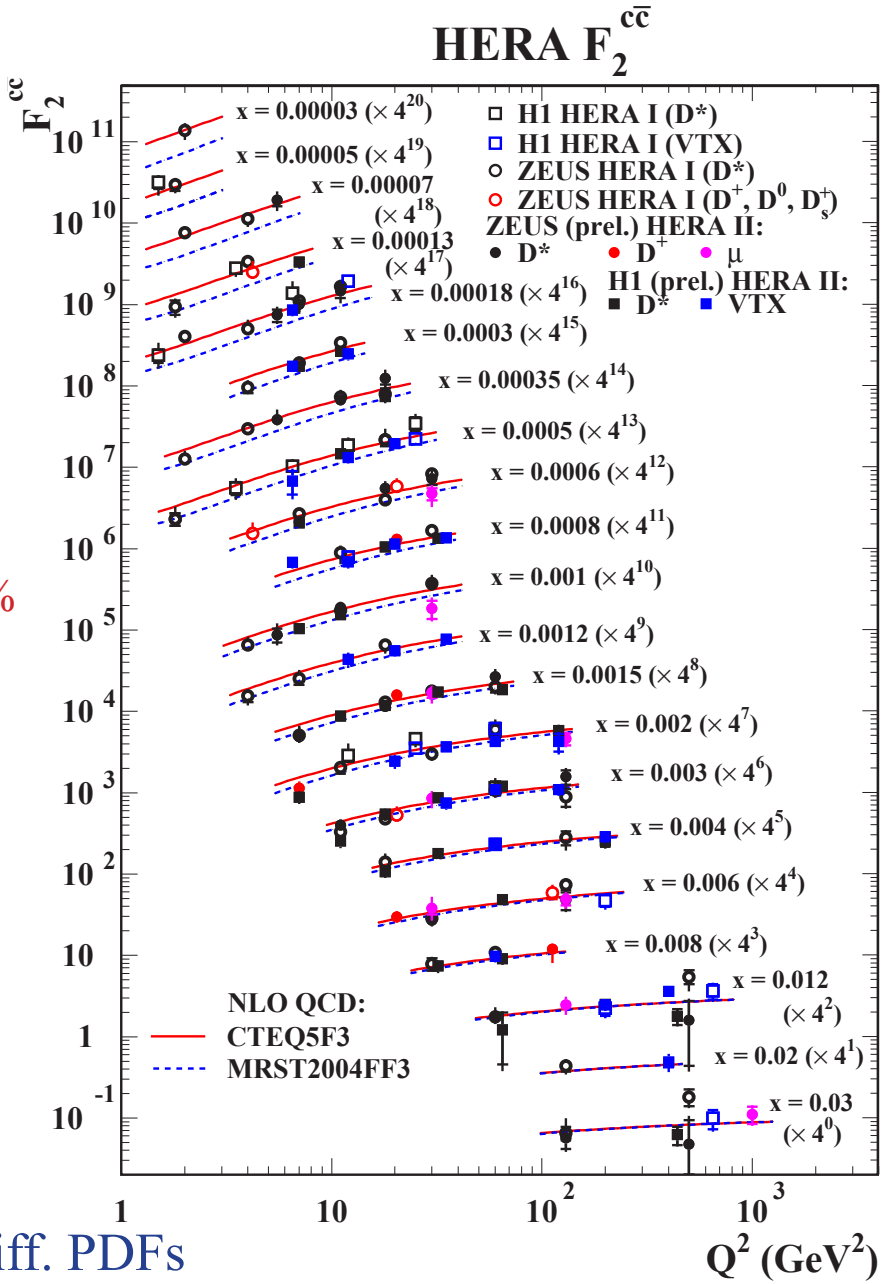
→ $F_2^{c\bar{c}}, F_2^{b\bar{b}}$

Measurements of $F_2^{c\bar{c}}$

$$\frac{d^2\sigma^{c\bar{c}}}{dx\,dQ^2} = \frac{2\pi\alpha^2}{Q^4 x} Y_+ \left[F_2^{c\bar{c}}(x,Q^2) - \frac{y^2}{Y_+} F_L^{c\bar{c}}(x,Q^2) \right]$$

for low Q^2 with $Y_+ = (1+(1-y)^2)$

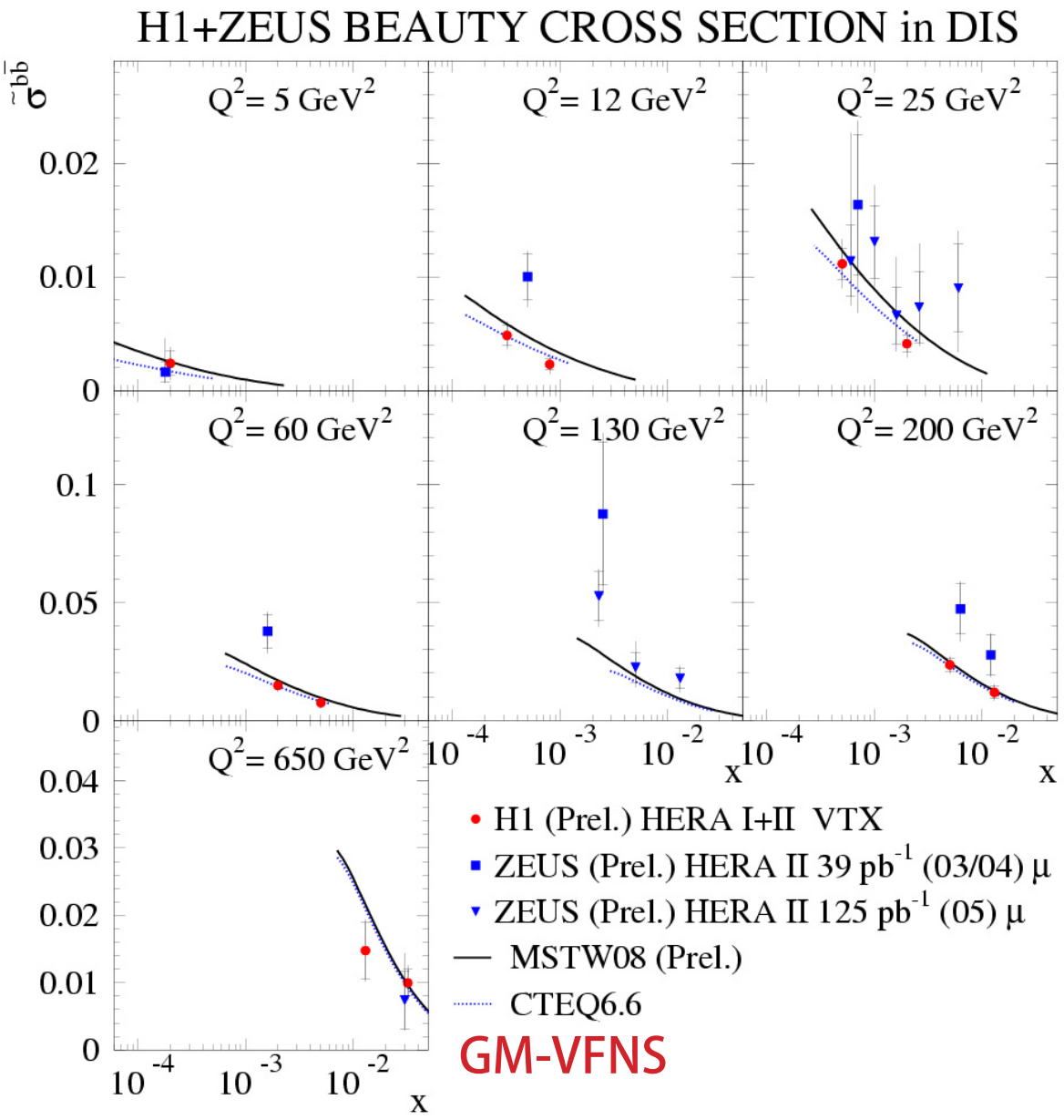
negligible: 2%



- good agreement among different techniques and datasets
- clear scaling violations at low x and towards large Q^2
- reasonable agreement with NLO predictions (FFNS) based on different PDFs
- precision high enough to distinguish between diff. PDFs

Measurements of $F_2^{b\bar{b}}$

- definition analogous to F_2^{cc}
- agreement among
  different datasets
- strong rise towards low x at large Q^2
- large experimental uncertainties
- not possible to distinguish between
  different parton densities



Summary and Conclusion

Small fraction of HERA Heavy Flavor results presented

D* Cross Section measurements in γp and DIS

- data are reasonbly described by NLO pQCD over a wide kinematic range
- fragmentation: open issues when the D* is produced close to the threshold

Beauty/Charm production

- via semileptonic decays (p_t^{rel})
- inclusive lifetime tag (signed impact parameter)

Extraction of F_2^{cc} and F_2^{bb}

- good agreement among different techniques and datasets
- charm data is sensitive to PDFs

Backup

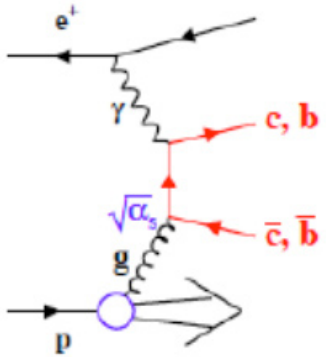
pQCD aproximations

Multiscale problem: different approaches to treat the heavy quark mass

Massive scheme:

- c, b massive
- neglects $\alpha_s \ln (Q^2, p_t^2 / m^2_{c,b})$
- massive reliable at small Q^2, p^2_t

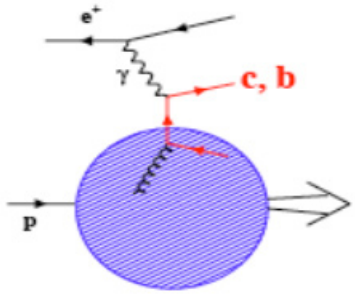
c, b produced dynamically

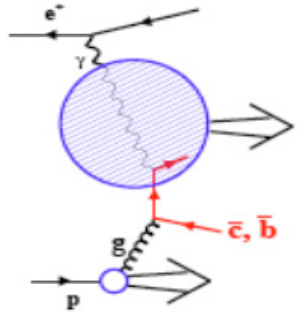


Massless scheme:

- c, b massless
- resums $\alpha_s \ln (Q^2, p_t^2 / m^2_{c,b})$
- massless reliable at small Q^2, p^2_t

c, b active in Proton/Photon structure functions





General Mass Variable Flavour Number Scheme (GM-VFNS):

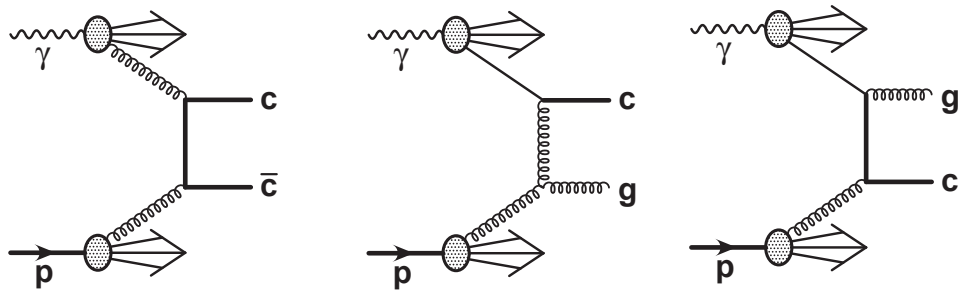
- Intermediate (or variable) scheme, massive at small Q^2, p^2_t, massless at high Q^2, p^2_t

Predictions for Heavy Quark Production

Monte Carlo: LO + Parton Shower

- DGLAP evolution (collinear factorization)
  - RapGap (DIS)
  - Pythia, Herwig (γp)
- CCFM evolution (k_t factorization)
  - Cascade (γp, DIS)

- in Photoproduction (γp) contributions of resolved processes:



hadron like charm flavour exitation

Hemisphere Method

Reconstruction of energy of the charm quark:

- all particles with $\eta > 0$ in γp-frame
- project onto plane in proton direction
- get thrust axis
- all particles momenta of particles in D* hemisphere