Heavy Flavour Production at HERA

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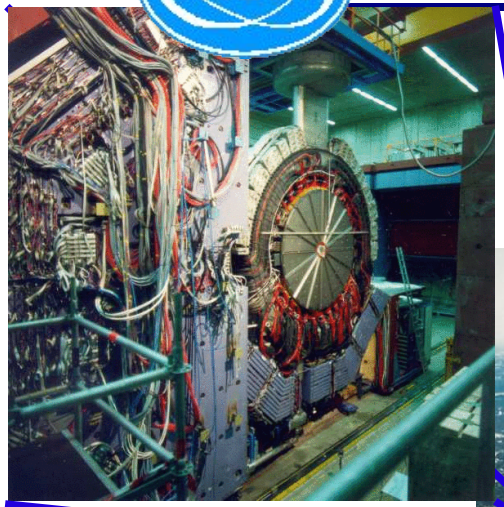
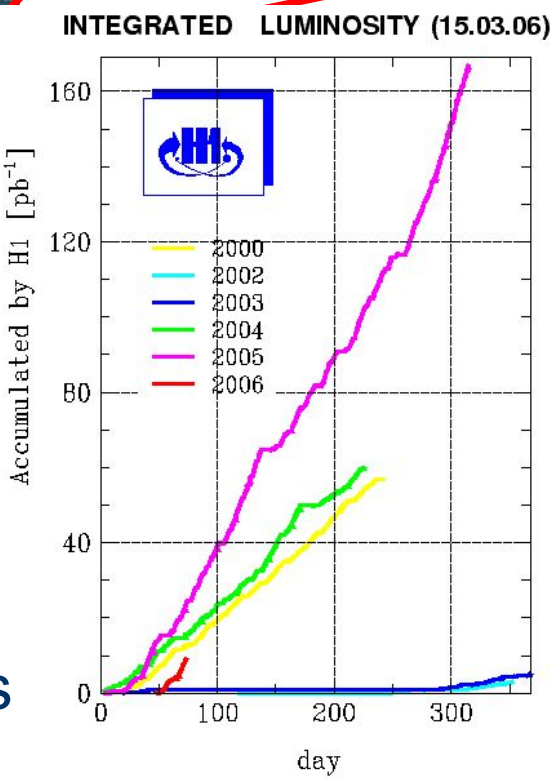
XLI[st] Rencontres de Moriond on QCD 2006

La Thuile, March 20, 2006

- Introduction
- Charm Production
- Beauty Production

HERA, H1, and ZEUS



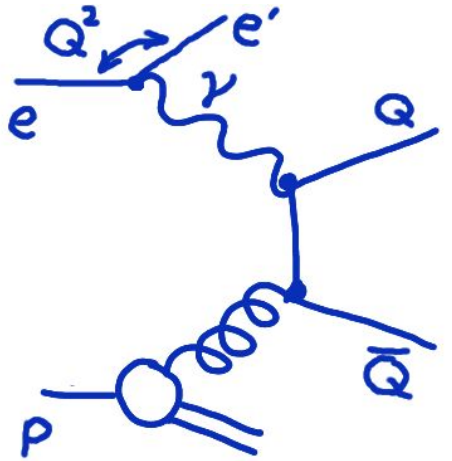


- 27.5GeV e± on 920GeV p => √s=320GeV
- HERA-I: 1992-2000: => publications
- HERA-II: 2003-2007: => 1st preliminary results

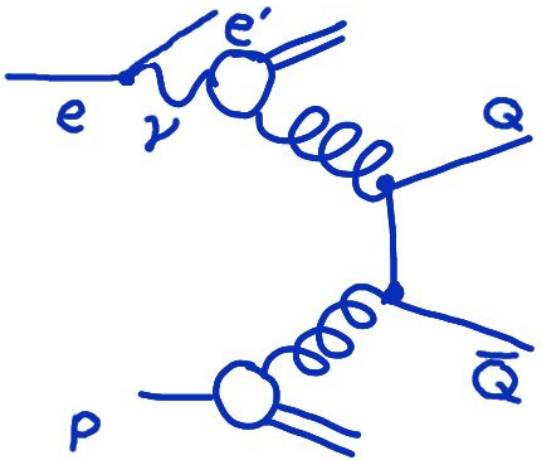
Heavy Flavour Production in ep Scattering

- Mechanism: Boson gluon fusion
- Expect 2 charm/beauty jets back to back
- Different scales to make α_s small:
  - Quark mass (fully inclusive photoproduction)
  - Jet p_t (photoproduction with jets)
  - Photon virtuality (deep inelastic scattering DIS)
- Theoretical challenges:
  - Massive vs. massless treatment of heavy quarks
  - Intrinsic gluon k_t
  - Direct vs. resolved production
- x_γ^{obs}: Fraction of photon momentum carried by jet pair: Distinguishes between direct ($x_\gamma \sim 1$) and resolved ($x_\gamma << 1$) production

„Direct“



„Resolved“



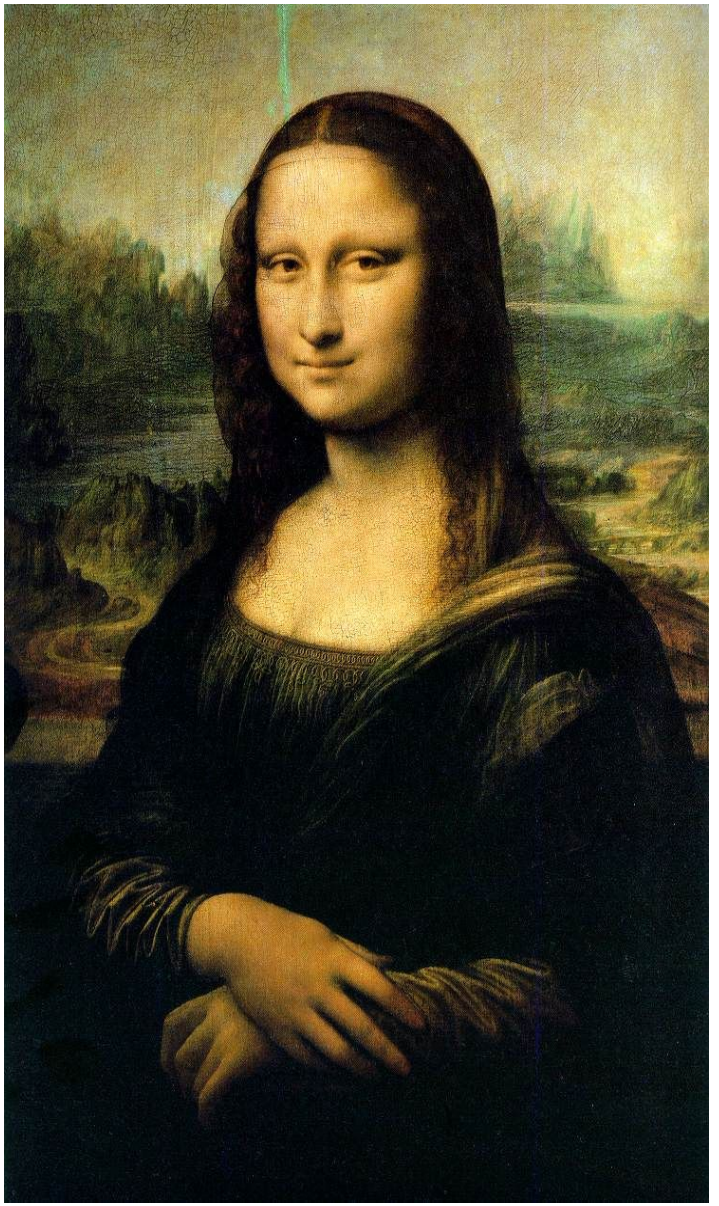
Charm

Techniques:

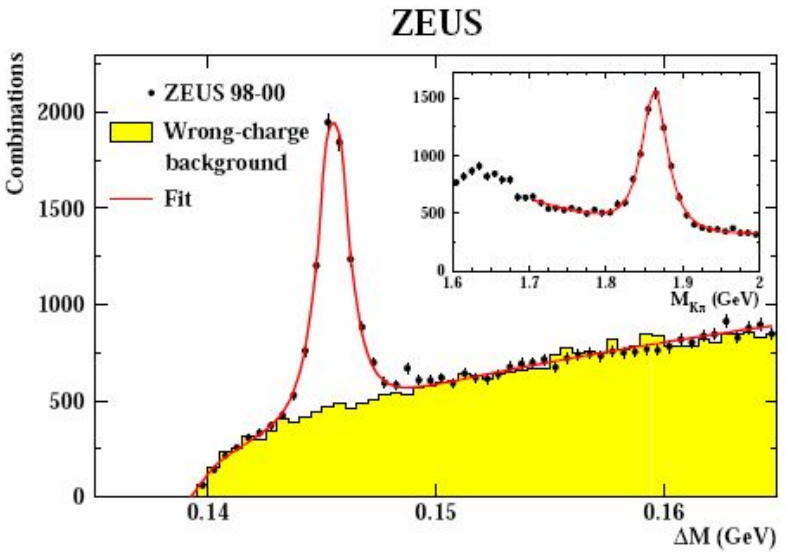
- D* tagging
- Lifetime tagging

Results:

- Charm + jets cross sections
- Inclusive cross sections in DIS

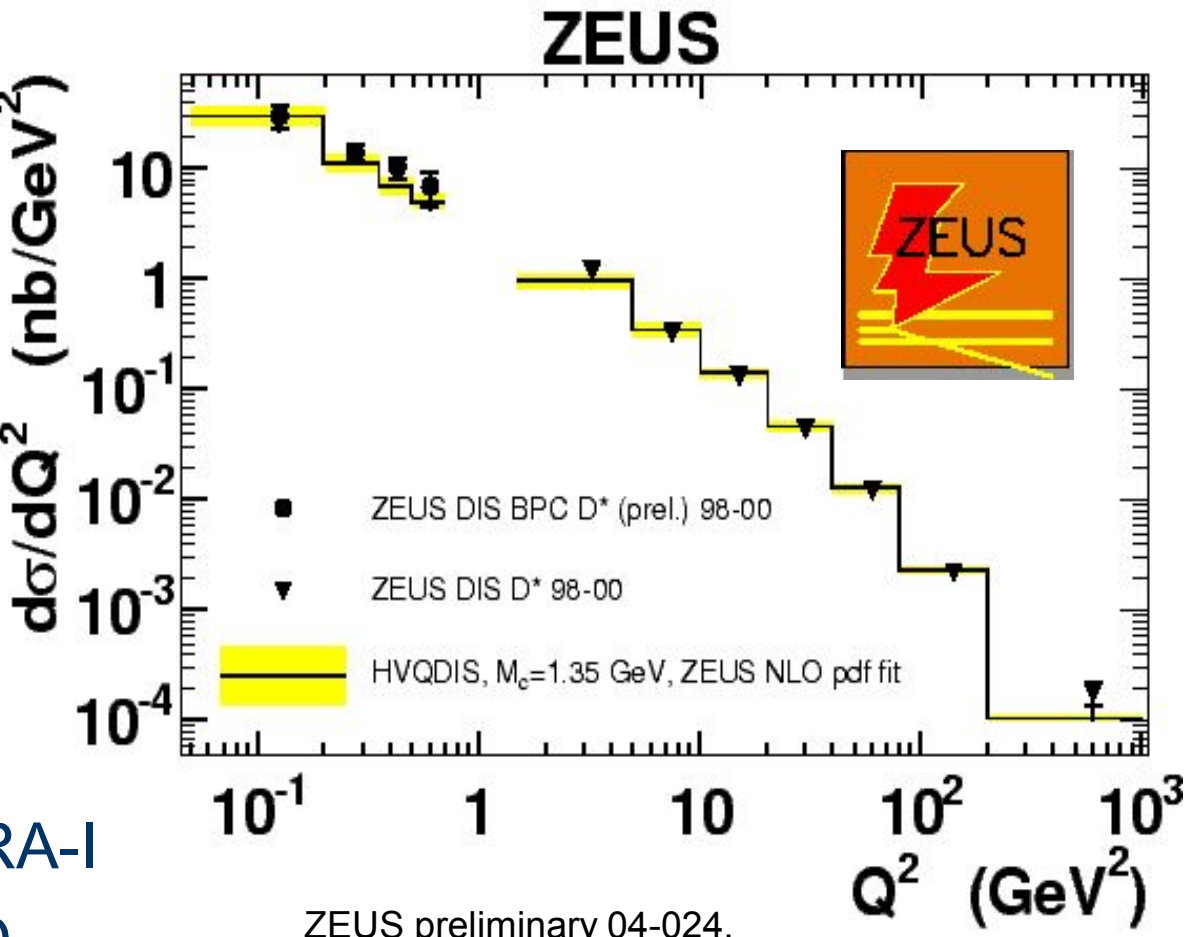


Charm Tagging via D* Production



ZEUS, PR **D69** (2004) 012004.

$$D^* \rightarrow (K\pi)\,\pi_s$$

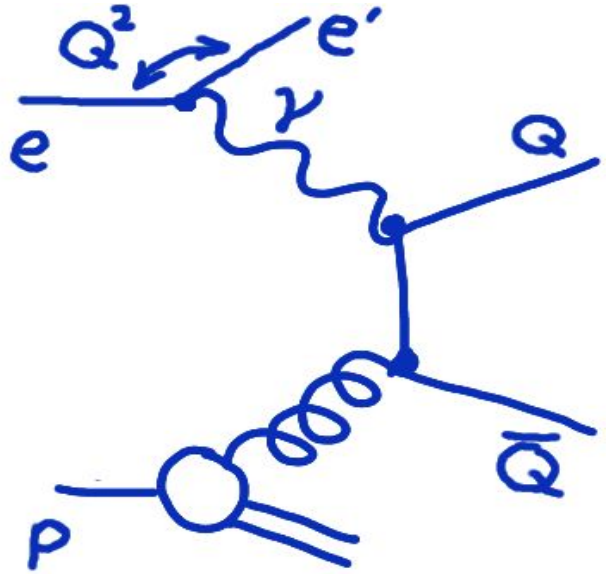


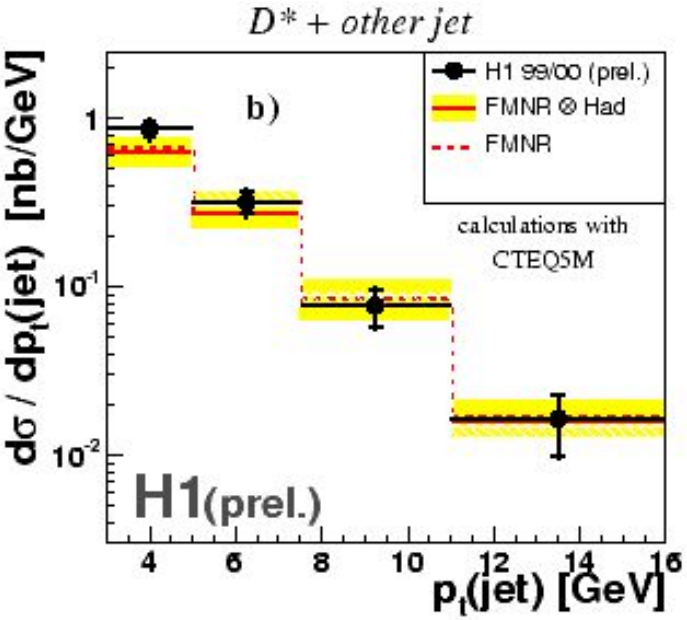
ZEUS preliminary 04-024.
ZEUS, PR **D69** (2004) 012004.

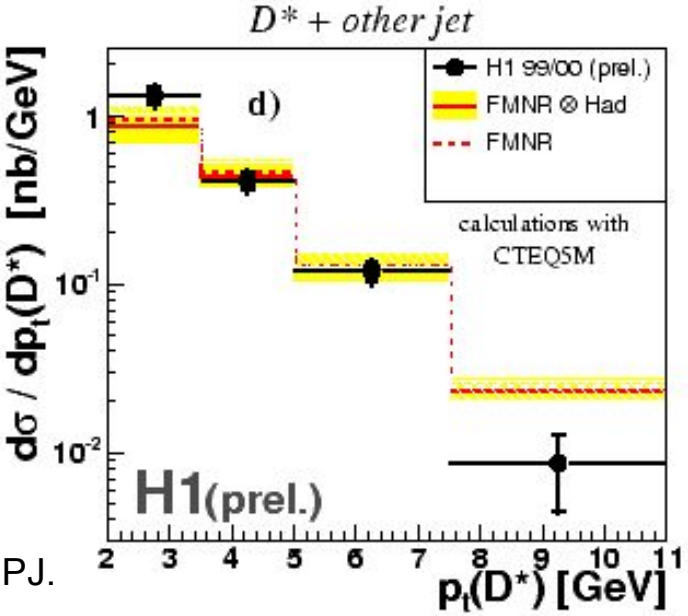
- Large D* Samples from HERA-I
- Well described by NLO QCD
- Q^2 evolution measured over 4 orders of magnitude

Charm with Jets in Photoproduction

- H1 measurement:
  - Events with a reconstructed D* + 2nd jet in photoproduction
- p_t spectra of D* and jet well described by NLO QCD (FMNR Frixione *at al.* PL B348(1995) 63)



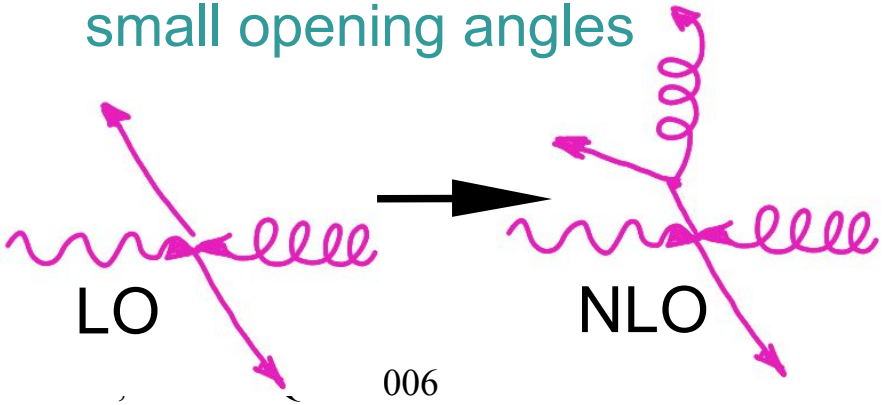




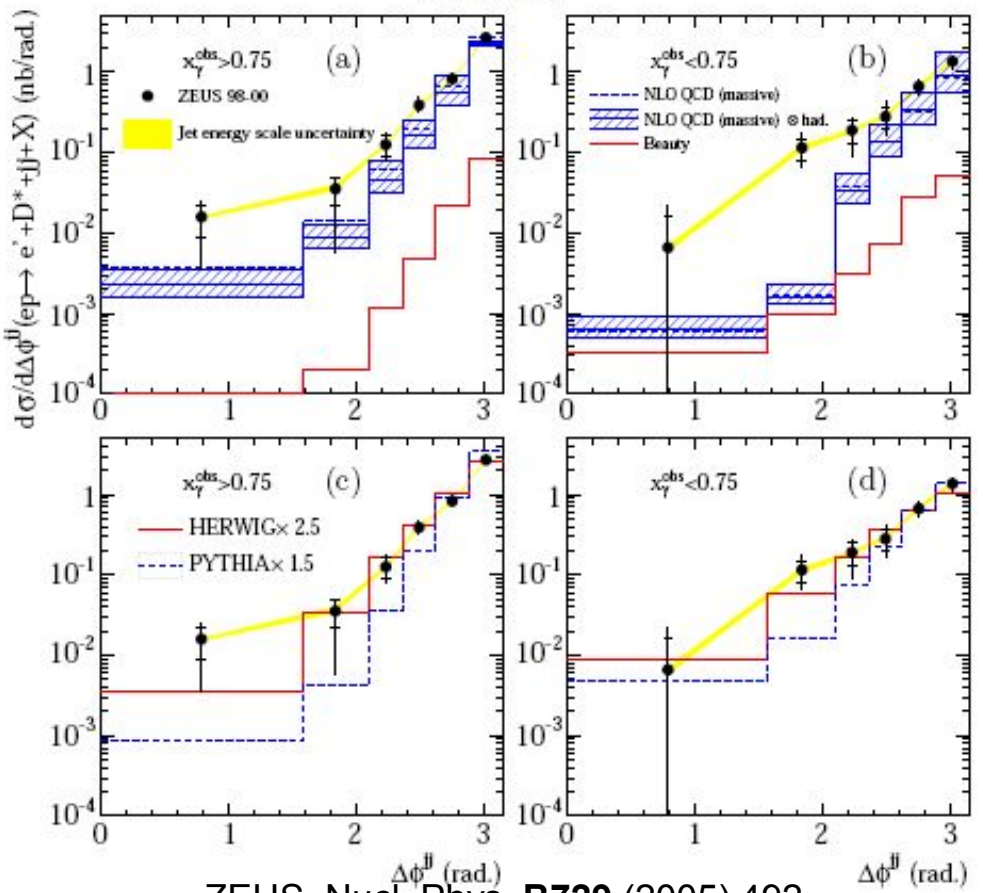
H1prelim-05-073, to be published in EPJ.

Dijets with Charm: Testing NLO QCD

- Leading order: Quarks are back-to-back
- Additional gluons: Angle between jets smaller than π
- ZEUS measurement:
  - Dijet event in photoproduction
  - D* tagged
- Direct part (x_γ^{obs}>0.75):
  - Reasonably described by massive NLO QCD (FMNR)
- Resolved part (x_γ^{obs}<0.75):
  - NLO QCD undershoots data at small opening angles

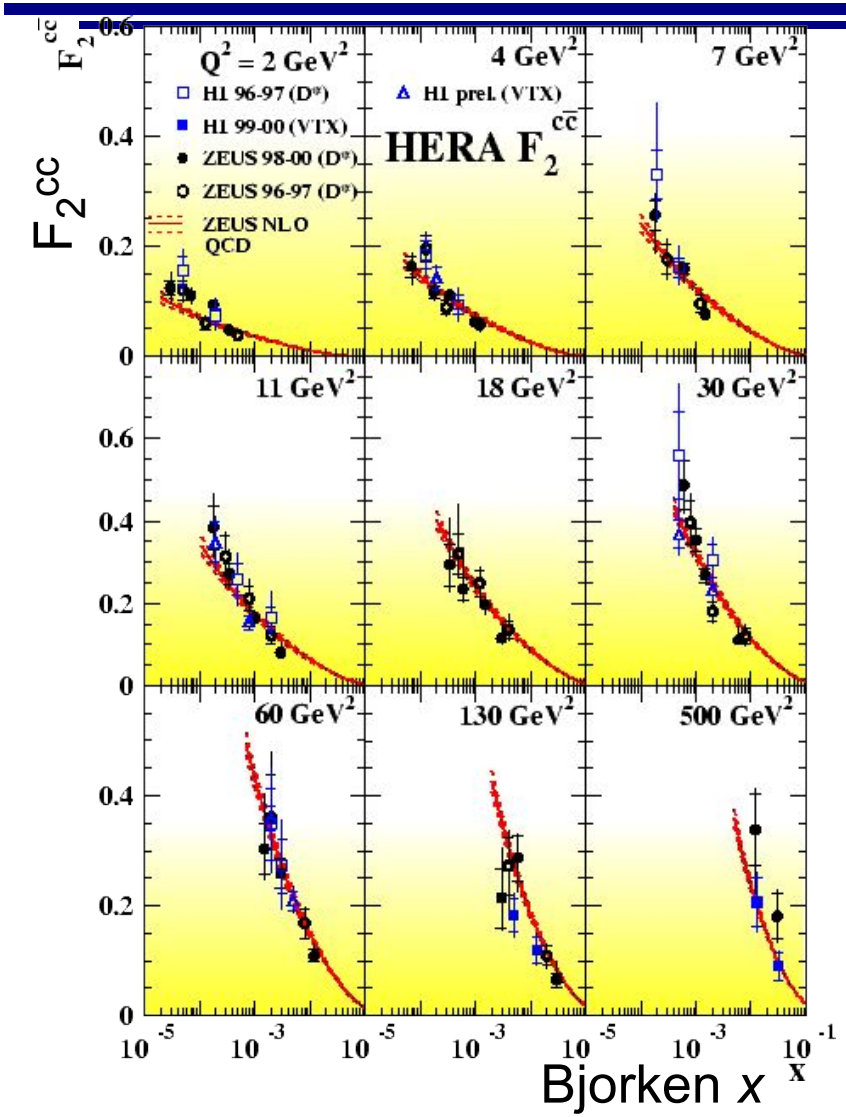


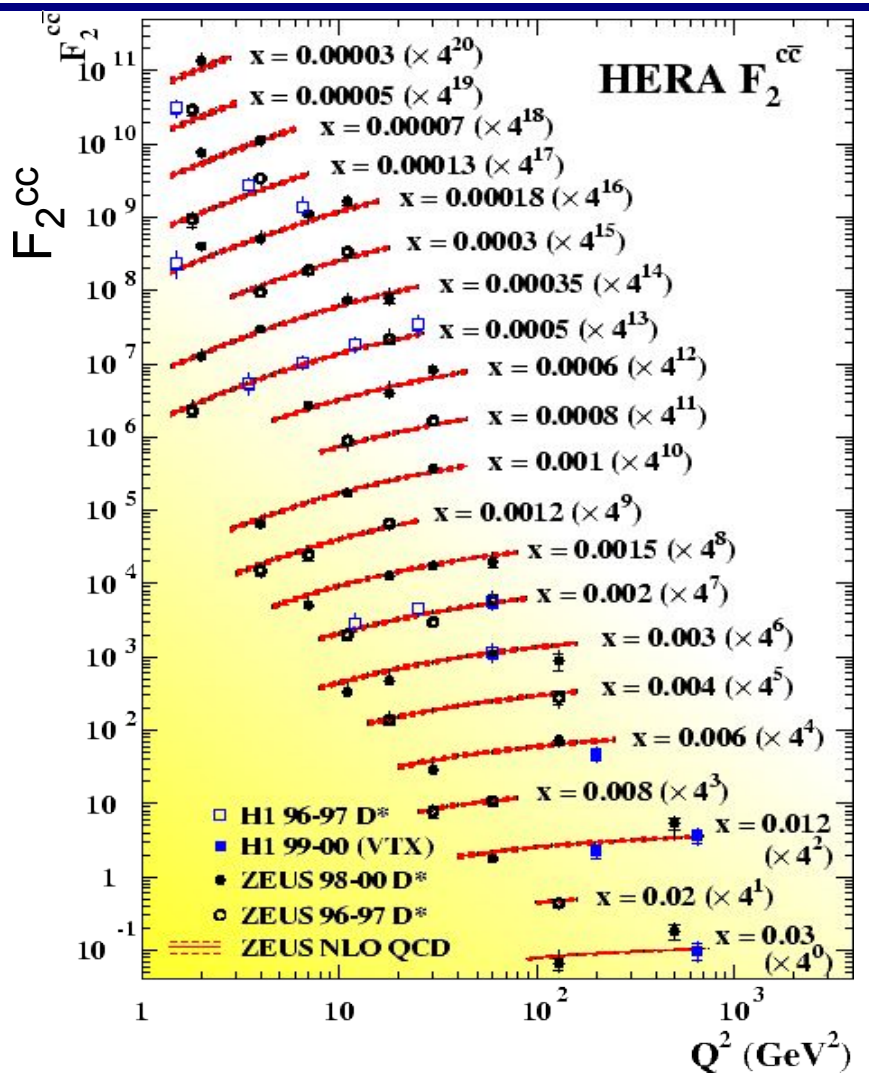
„Direct“ (x_γ^{obs}>0.75) **„Resolved“ (x_γ^{obs}<0.75)**



ZEUS, Nucl. Phys. **B729** (2005) 492.

Charm in DIS ($F_2^{c\bar{c}}$): The Harvest from HERA-I





- NLO QCD fit with gluon from inclusive DIS fits well
- At low Q^2: Slight deviations; Charm constrains gluon better than F_2

ZEUS, PR **D69**(2000)012004.
H1, EPJ **C40** (2005) 349.
H1, EPJ **C45** (2006) 23.

Beauty

Techniques

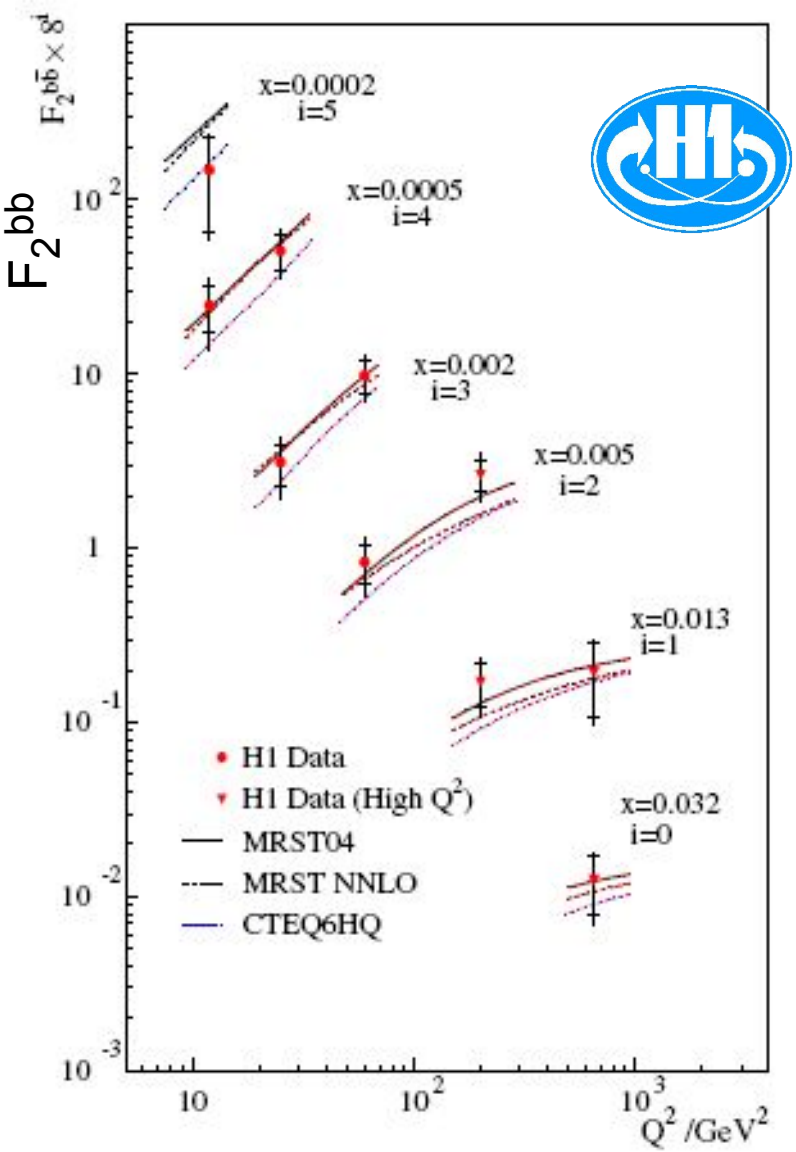
- Lifetime tagging
- Semileptonic decays: Jets+Muons
  - Relative p_t
  - Additonal lifetime information

Results:

- Inclusive cross sections (F_2^{bb})
- Visible cross sections

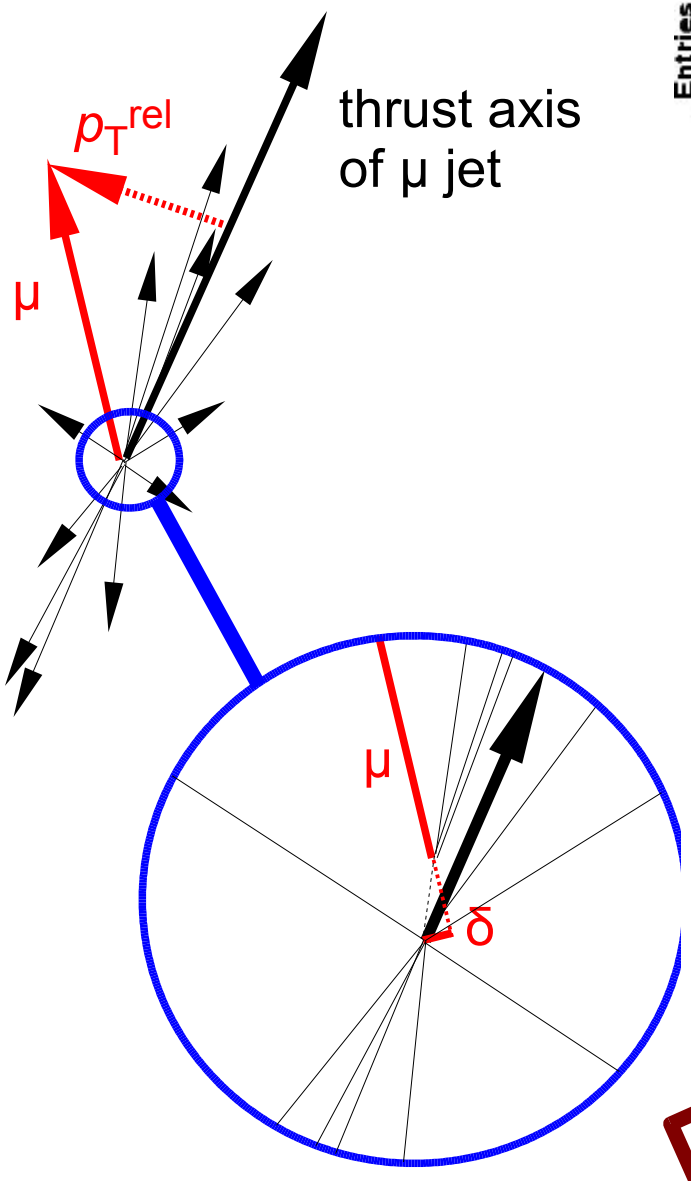
Inclusive Beauty Cross Section: F_2^{bb}

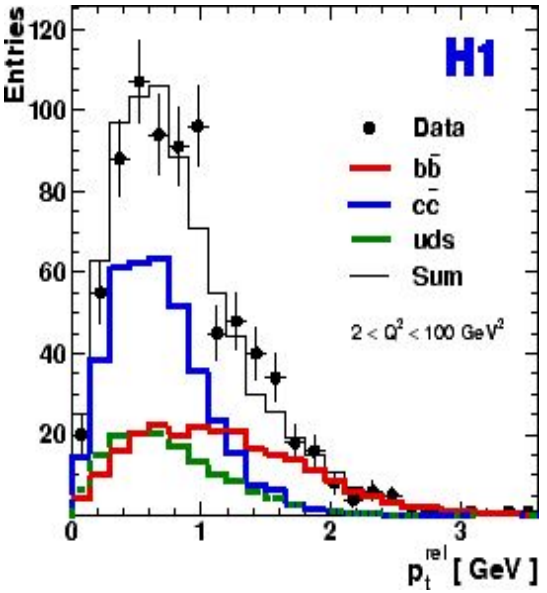
- H1: Uses lifetime tagging to extract charm and beauty together
  - First measurement of inclusive b production at HERA
  - Reasonably well described by NLO QCD
- First NNLO calculation available! (Thorne hep-ph/0506251)

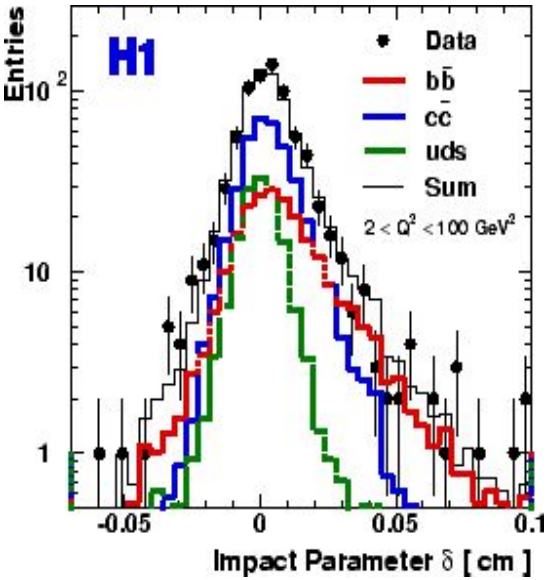


H1, EPJ **C40** (2005) 349.
H1, EPJ **C45** (2006) 23.

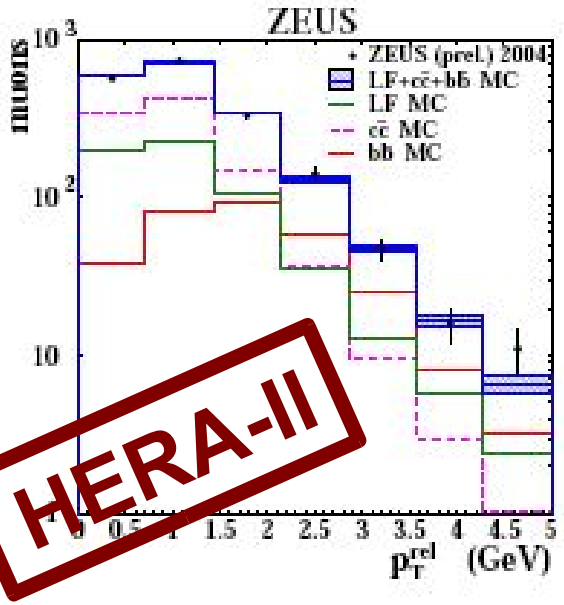
Measuring Beauty Production with μ+jets





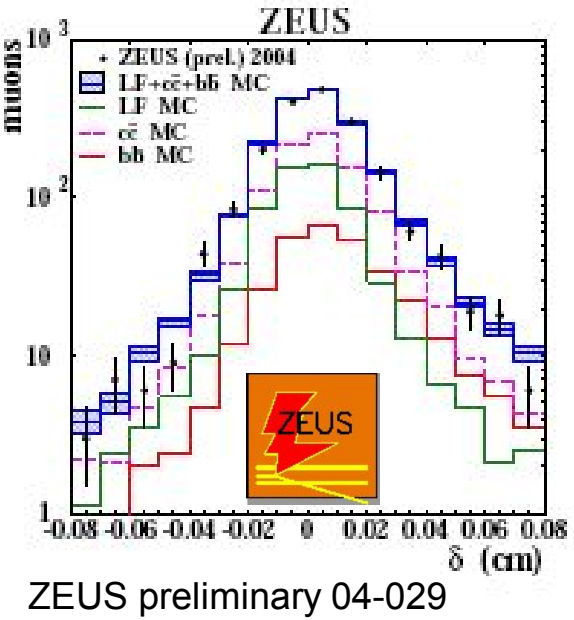


H1, EPJ **C41**(2005)453.



HERA-II

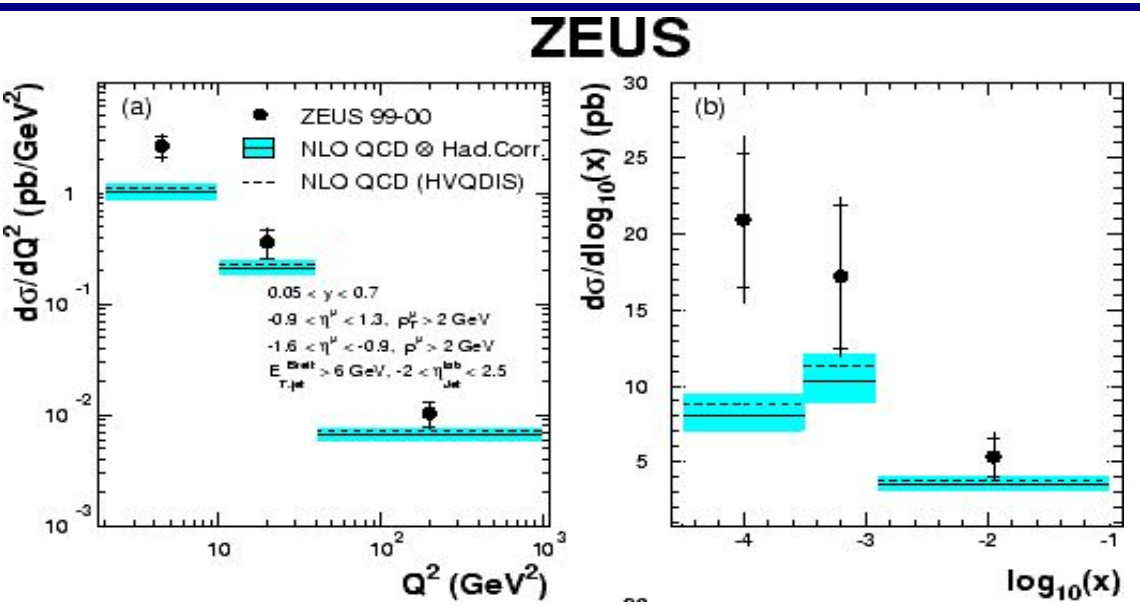
H1, hep-ex/0502106



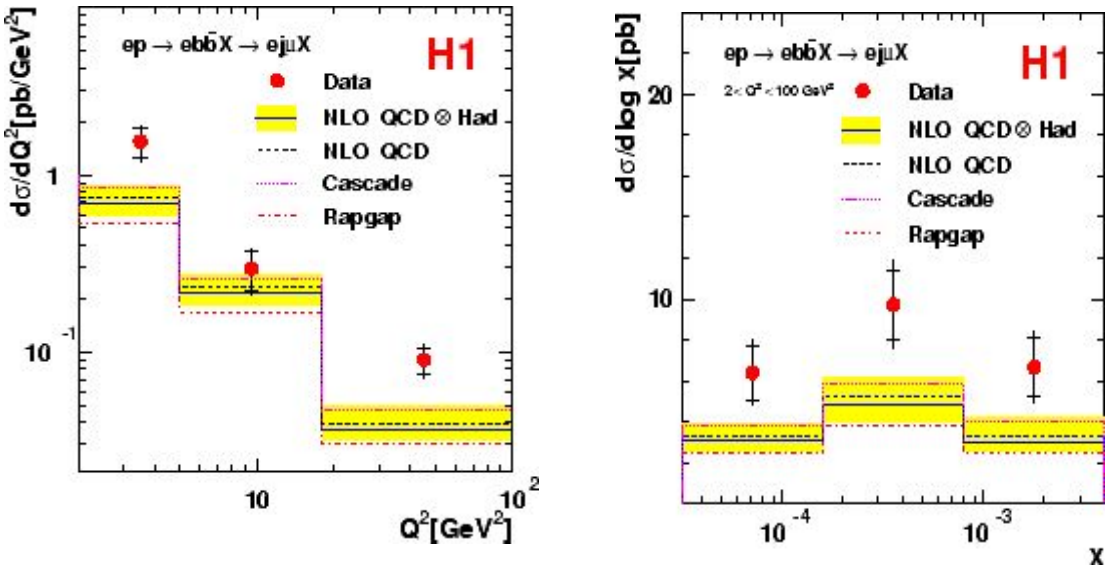
ZEUS preliminary 04-029

Visible Beauty Cross Sections

- At low Q^2<10GeV^2: Significant excess
- Excess at low x more pronounced
- A surprise: Would naively expect even better description than in charm case due to higher b mass
- Interplay between scales Q^2, p_t^2, and m_b^2?



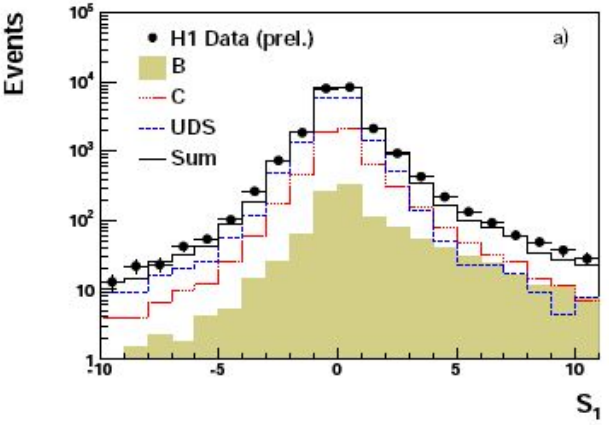
ZEUS, PL **B599** (2004) 173.

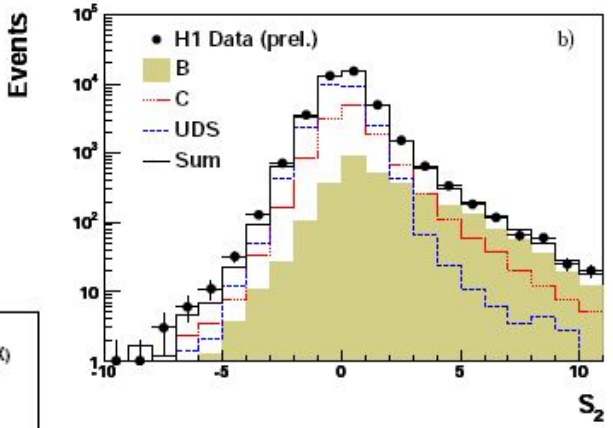


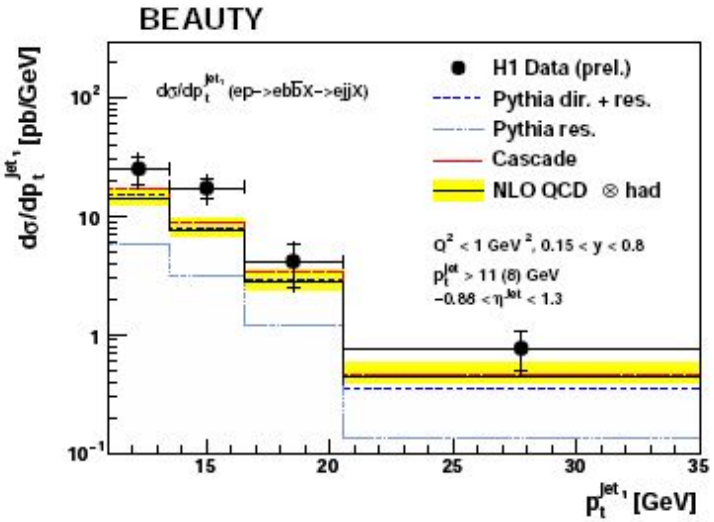
H1, EPJ **C41** (2005) 453.

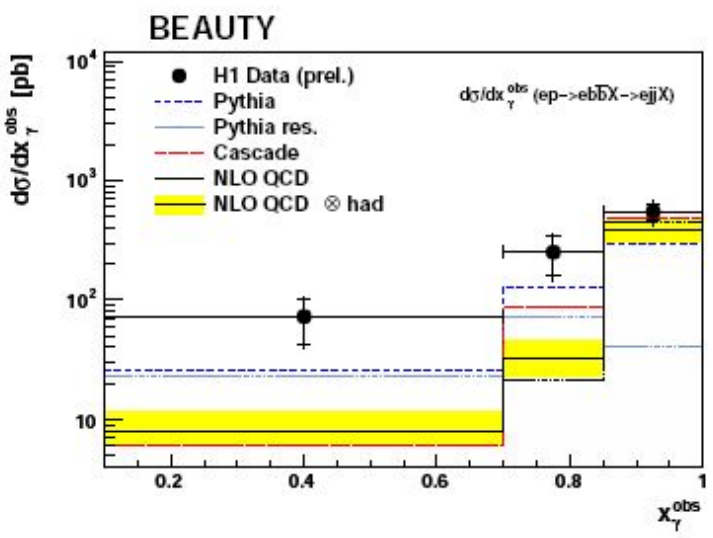
Beauty with Dijets in Photoproduction

- H1 analysis:
  - Photoproducion data
  - 2 jets with p_t>11 (8) GeV
  - Fit impact parameter distribution from silicon vertex detector for c&b fractions
- Jet p_t larger than c, b quark mass
- Excess over NLO QCD, mainly at low x_g^{obs} (resolved region)





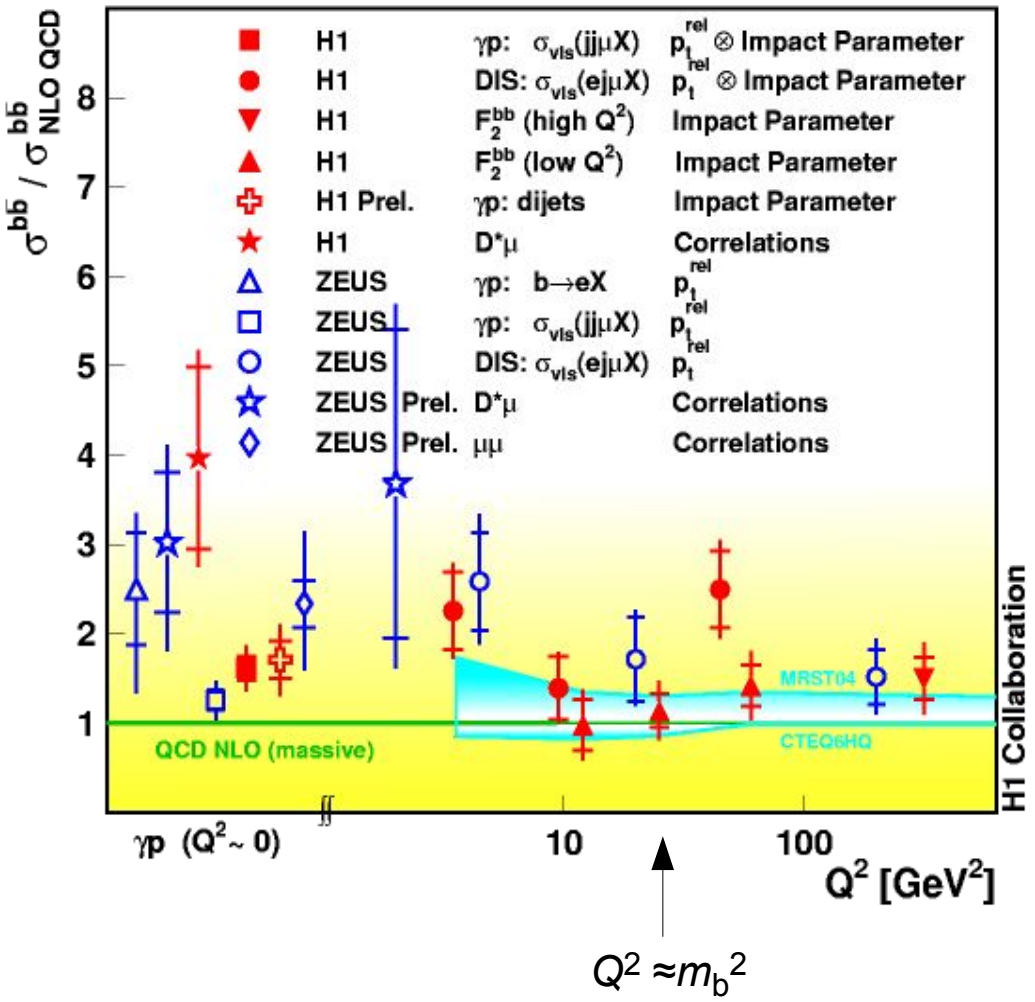




H1prelim-04-173,
publication in EPJ in progress

More Beauty than Expected

- All measurements consistent with a ratio data/NLO of 1.5
- Theory error (not shown) typically ~10%
- Improved theoretical understanding needed
- ... and underway:
  - NNLO calculations coming
  - Calculations taking gluon k_t into account



Conclusions and Outlook

- Charm production well described by NLO QCD
- Charm data precise enough to constrain the gluon at low Q^2
- Beauty production: headed for precision
  - Data above NLO predicition
- More and more HERA-II data coming in: the future is bright!