Heavy Flavour Production in DIS at HERA

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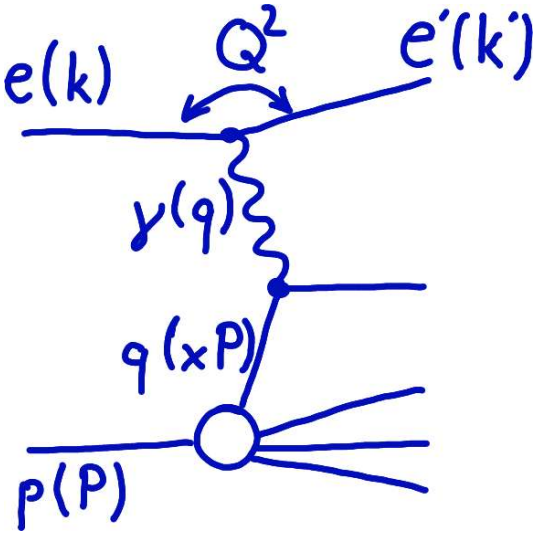
Institute for Particle Physics

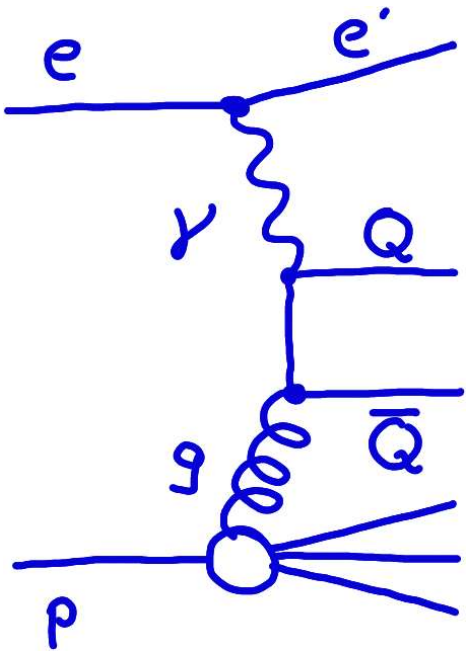
Beauty 2005

- Introduction
- Charm Production
- Beauty Production

Deep-Inelastic ep Scattering

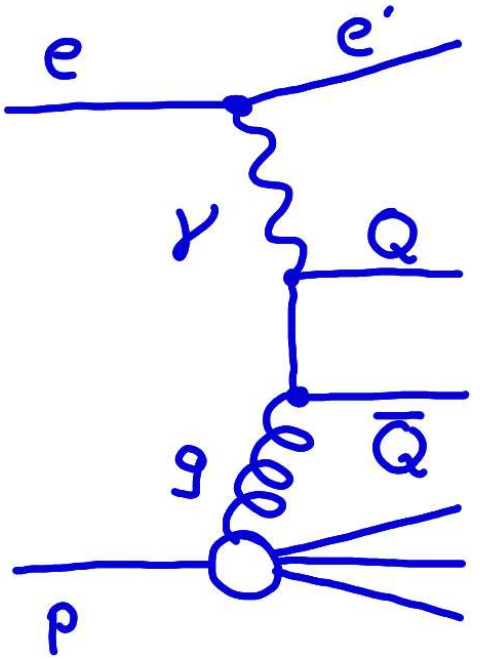
- Virtual photon of virtuality $Q^2=-q^2$ acts as pointlike probe
- Bjorken-x is momentum fraction of parton out of the proton
- „Light“ quark scattering ($m_q^2 << Q^2$) is described by a parton density within the proton
- Heavy quarks are produced dynamically by Boson-Gluon-Fusion
- Structure function F_2: Inclusive cross section, kinematic factors divided out





Theoretical Challenges

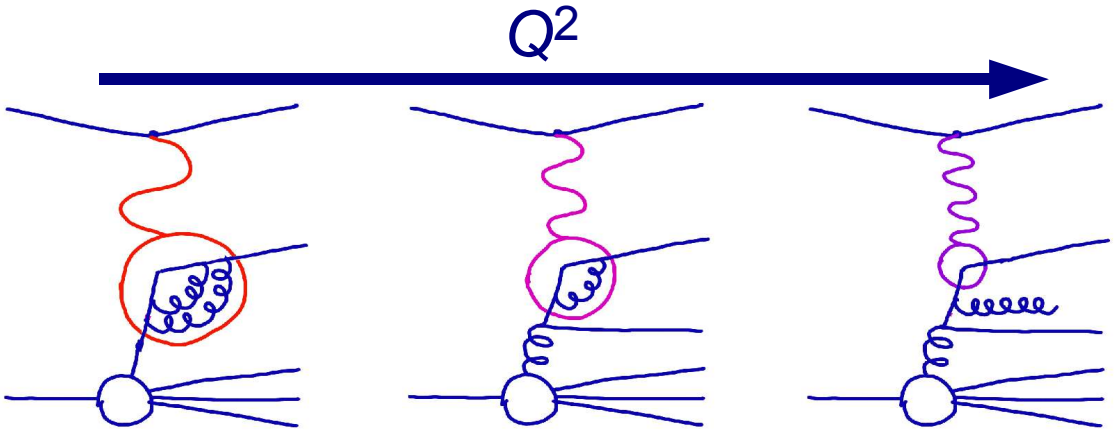
- Multi-Scale Problem: Hard scales Q^2, m_Q^2, p_T^2
- Treatment of Quarks:
  - „Massless“ quarks for $m_Q^2 < Q^2$
  - Massive quarks for $m_Q^2 > Q^2$
  - Transition region $Q^2 \approx m_Q^2$ difficult
  - Adressed by
    Variable Flavour Number Scheme VFNS
    (Lai, Tung; Chuvakin, Smith, Harris; Thorne, Roberts)



- Monte Carlo
  - LO Monte Carlo available (Pythia, Rapgap, Cascade)
  - NLO Calculations (HVQDIS), no full MCs with hadronization
  - => use LO MC for detector and hadronization effects,
    compare x-sections to NLO results

Heavy Flavours and the Gluon

- The gluon in the proton:
  - Drives the QCD evolution of the structure functions
    (at higher Q^2 = higher resolution, more quarks at low x are visible)
  - Generates heavy quarks via boson-gluon-fusion
- Gluon extracted from inclusive structure function measurements should lead to a correct prediction of charm production
- Heavy flavour (especially charm) production measurements can improve knowledge of gluon density in the proton
- Note: Charm contributes up to 35% to proton structure at high Q^2



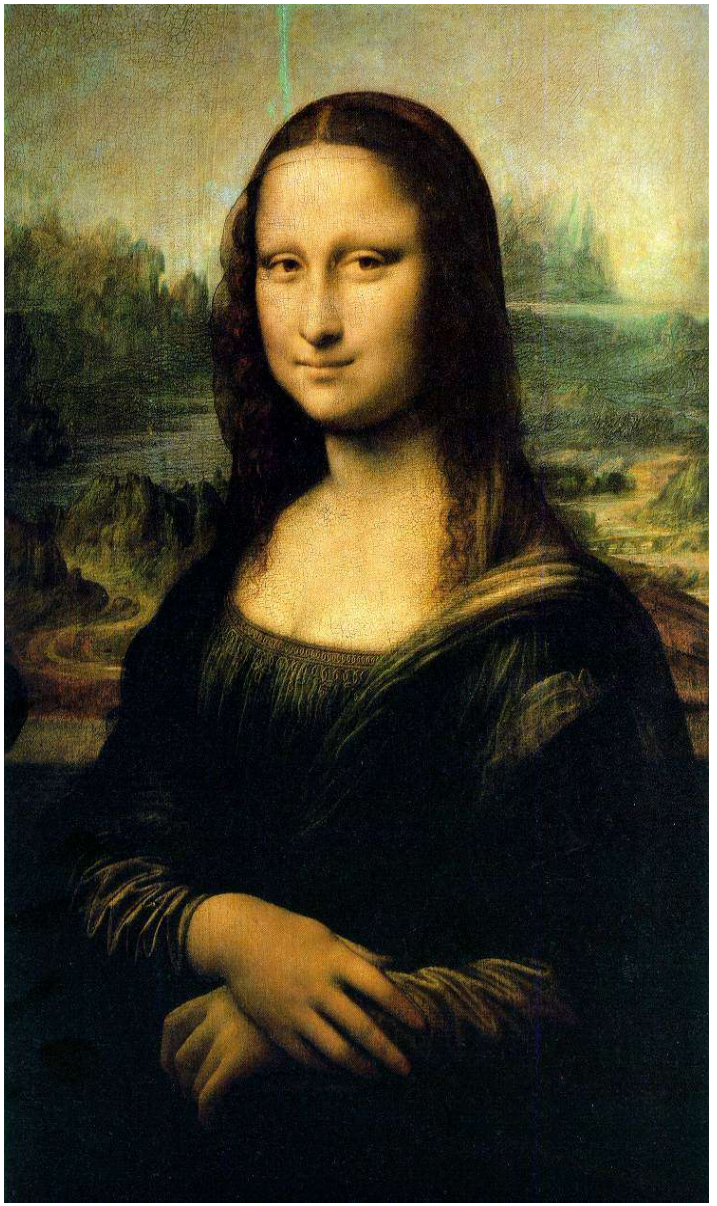
Charm

Techniques:

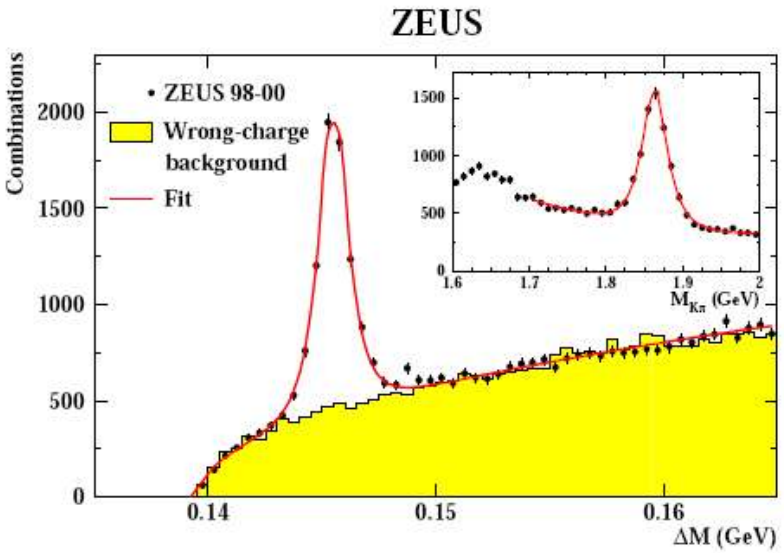
- D* tagging
- Lifetime tagging

Results:

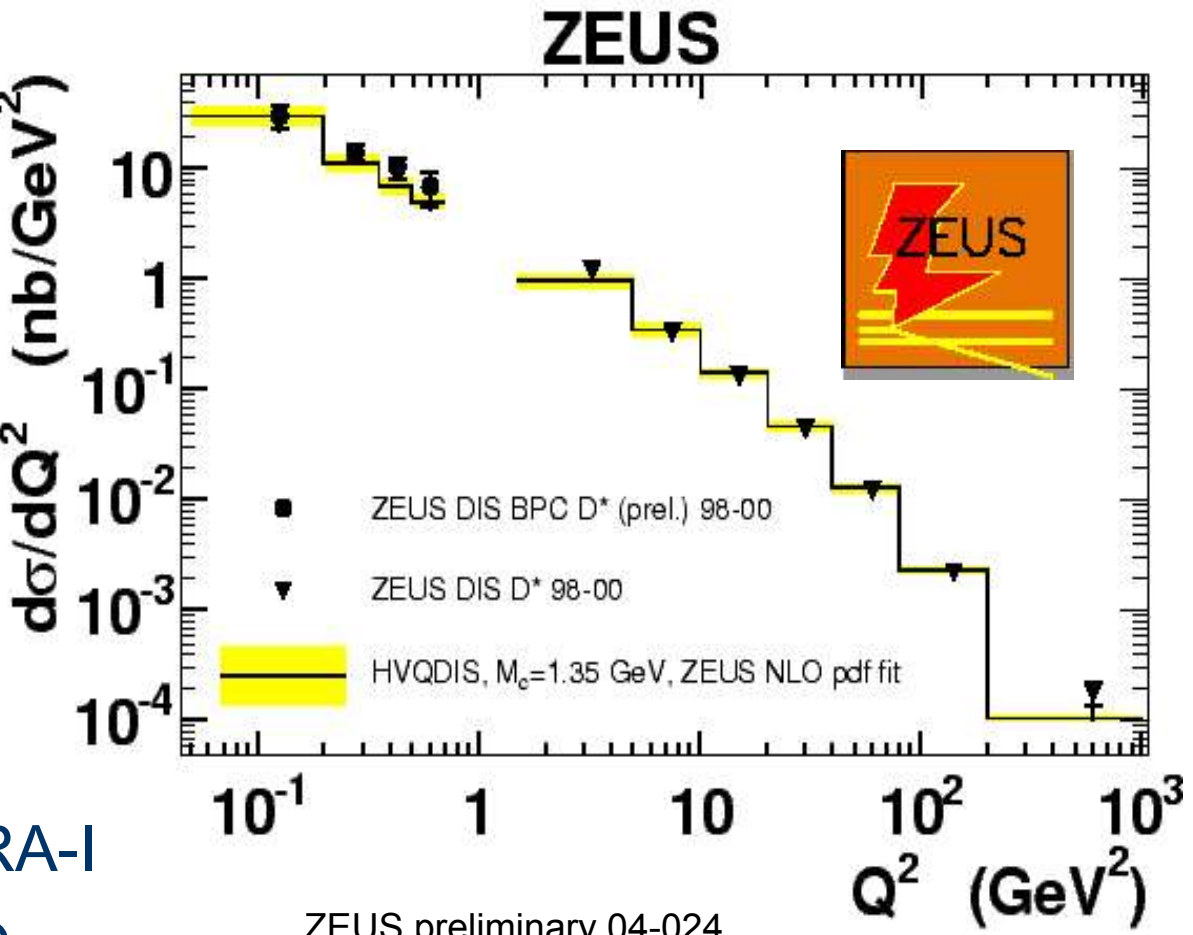
- Inclusive charm cross sections
- Fragmentation ratios



Charm Tagging via D* Production



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

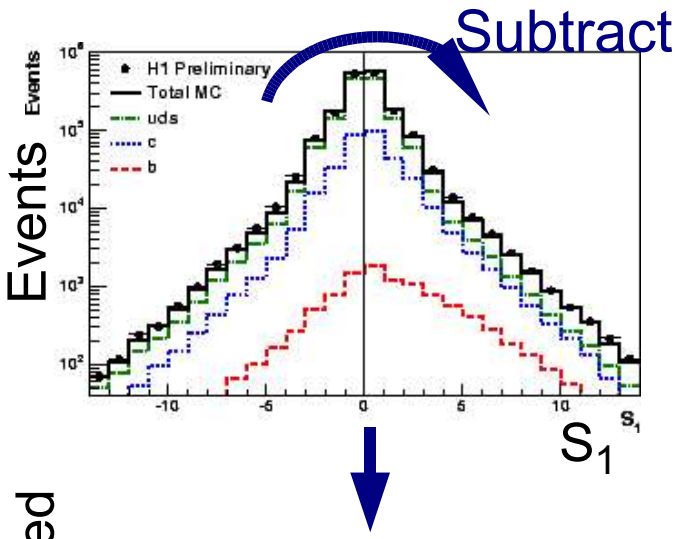


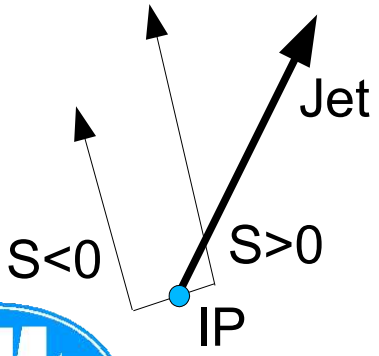
ZEUS preliminary 04-024.
ZEUS, PR **D69** (2004) 012004.

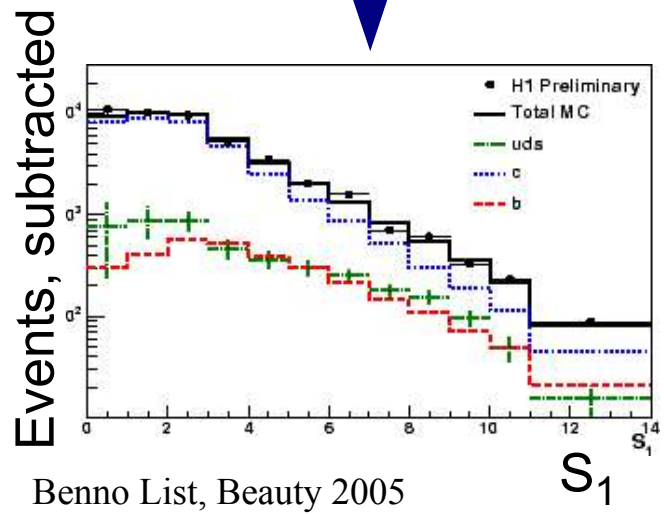
- Large D* Samples from HERA-I
- Well described by NLO QCD
- Q^2 evolution measured over 4 orders of magnitude

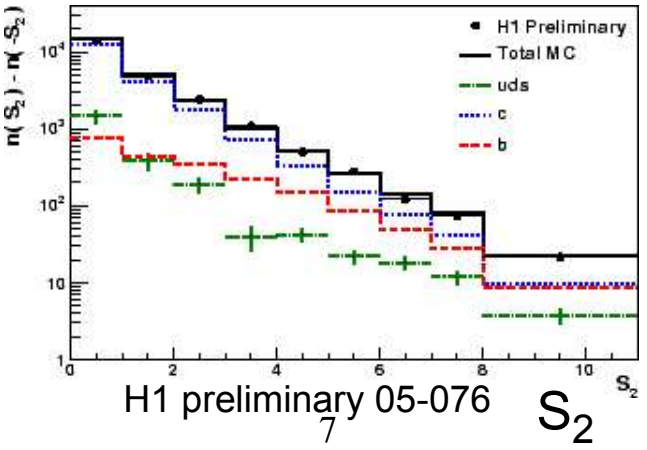
Charm from an Inclusive Lifetime Tag

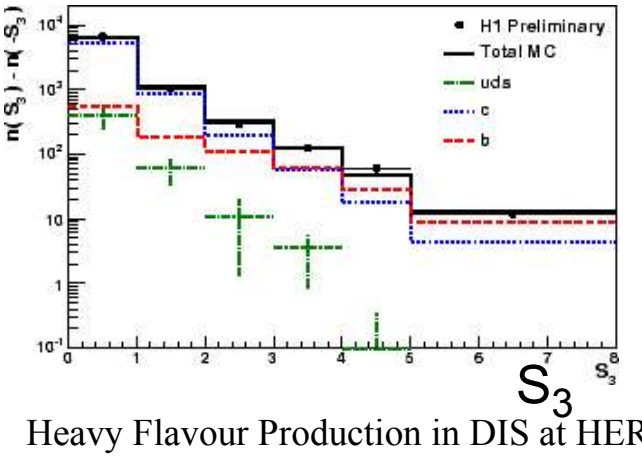
- Central Silicon Tracker resolves track impact parameters
- Measure Significances $S_i = \delta_i/\sigma\delta_i$, order them: $S_1 > S_2 > S_3$
- Use subtracted spectra to extract uds, c, and b



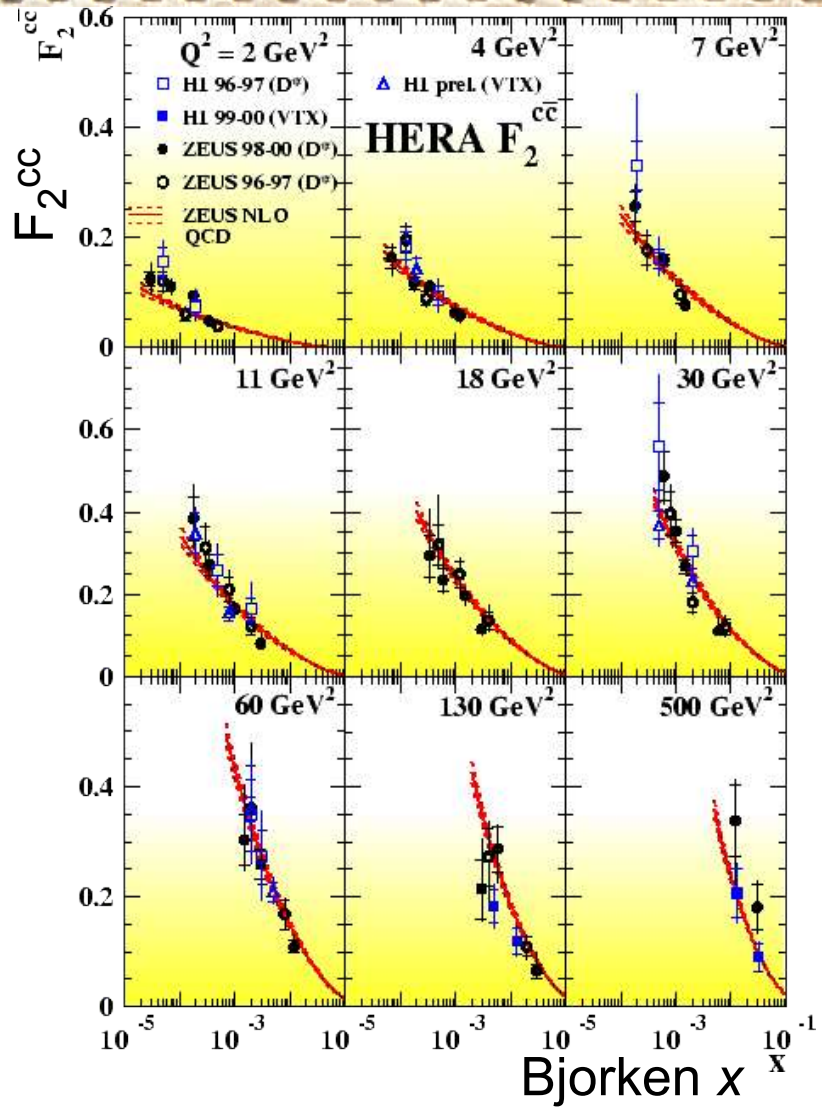


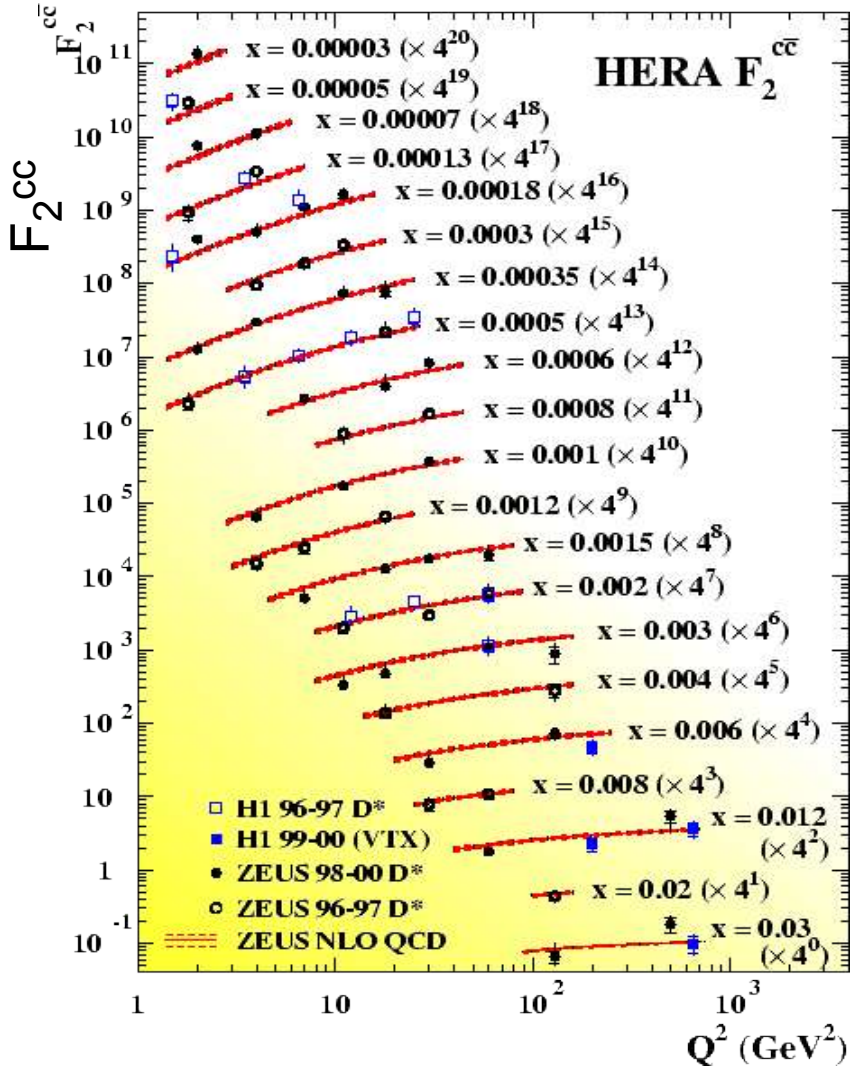






F_2^{cc}: The Harvest from HERA-I

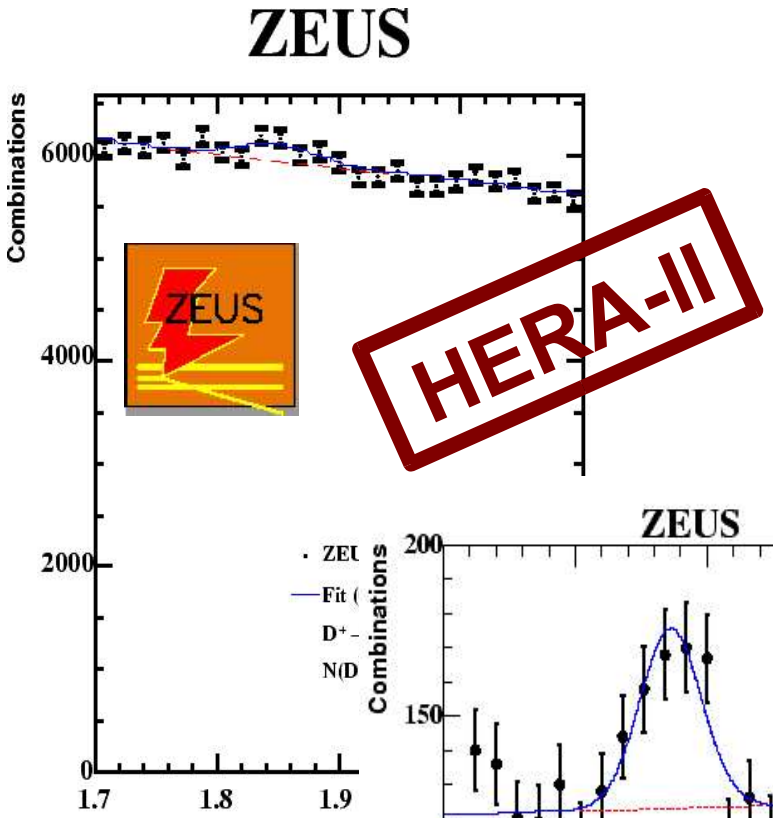


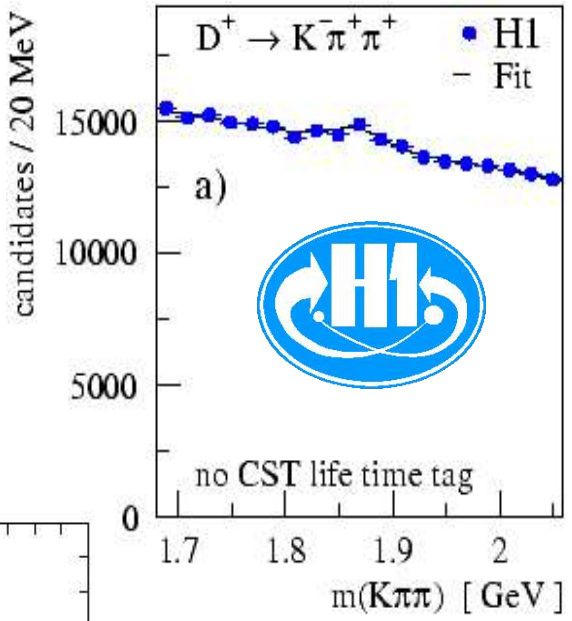


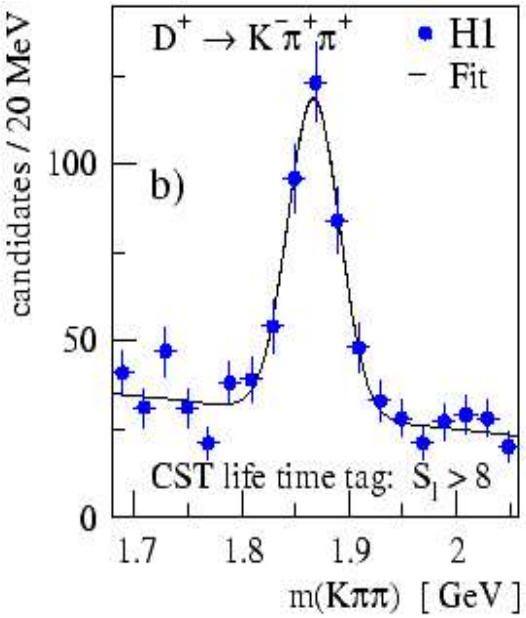
- NLO QCD fit with gluon from inclusive DIS fits well
- At low Q^2: Slight deviations; Charm constrains gluon better than F_2

ZEUS, PR **D69**(2000)012004.
H1, EPJ **C40** (2005) 349.
H1 preliminary 05-076,

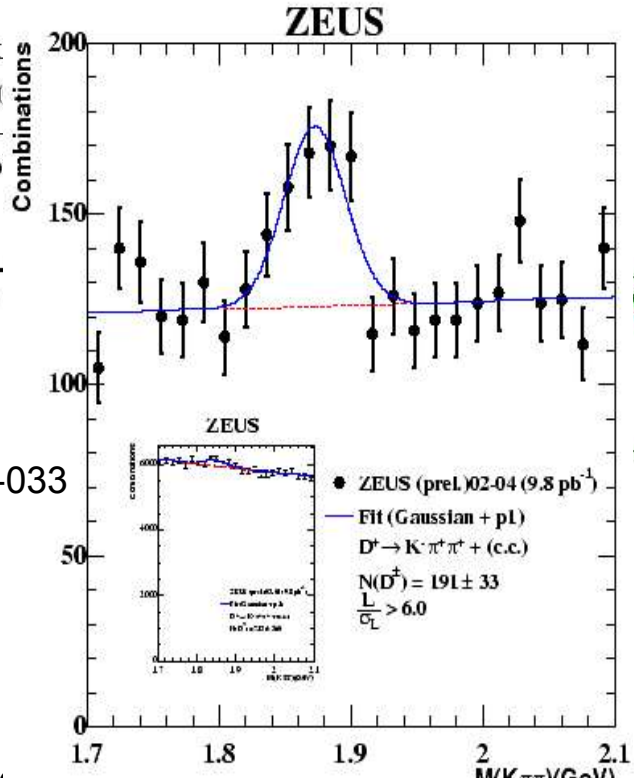
Lifetime Tagging: D^+ Signal



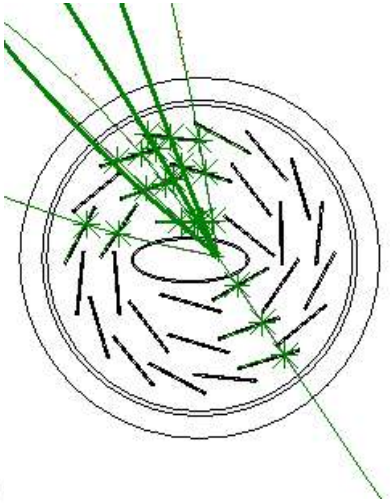


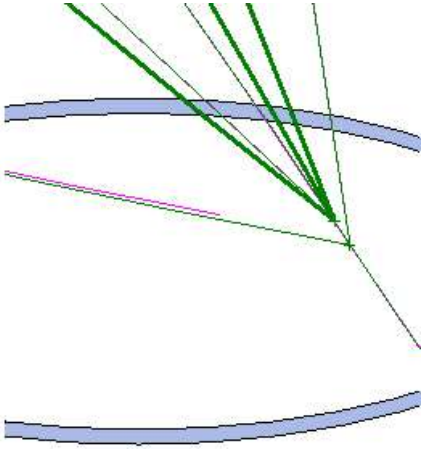


H1, EPJ **C38** (2005) 447.



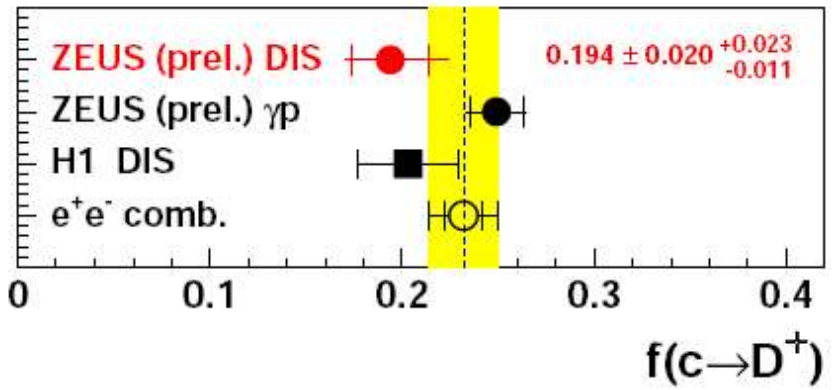
ZEUS preliminary 04-033

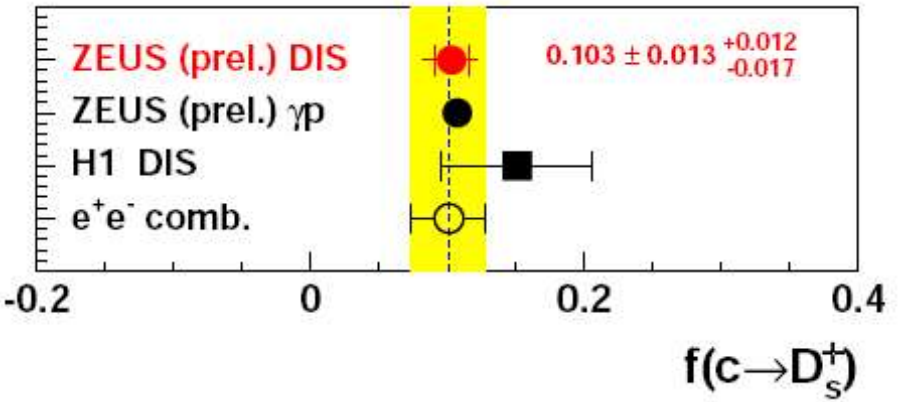


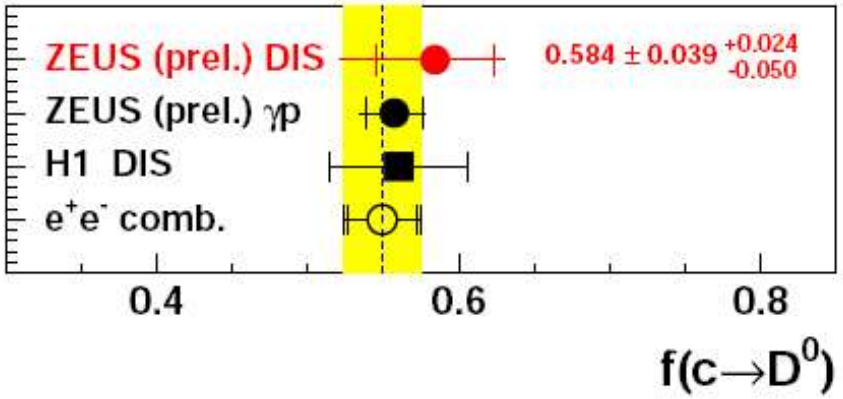


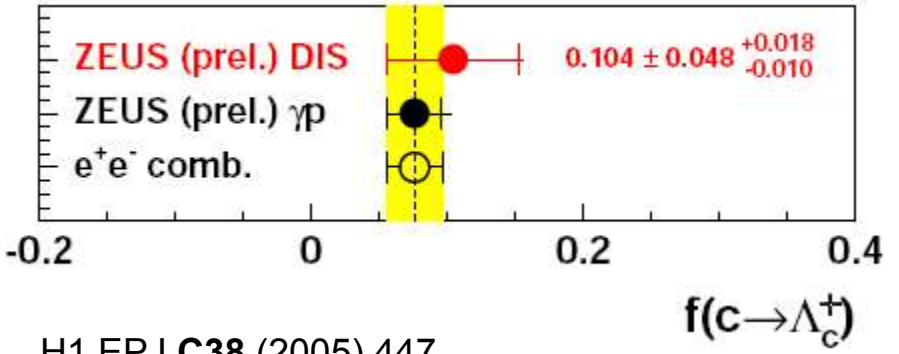
Fragmentation Ratios

- Measured by H1 and ZEUS
- Results consistent with e^+e^- data and of comparable precision









H1 EPJ **C38** (2005) 447.
ZEUS preliminary DIS2005.

Beauty

Techniques

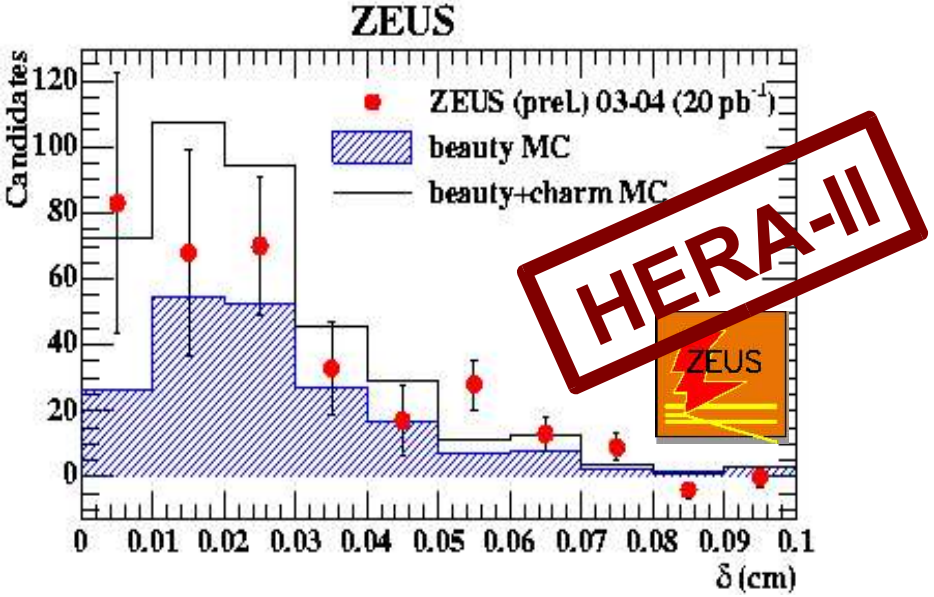
- Lifetime tagging
- Semileptonic decays: Jets+Muons
  - Relative p_t
  - Additonal livetime information

Results:

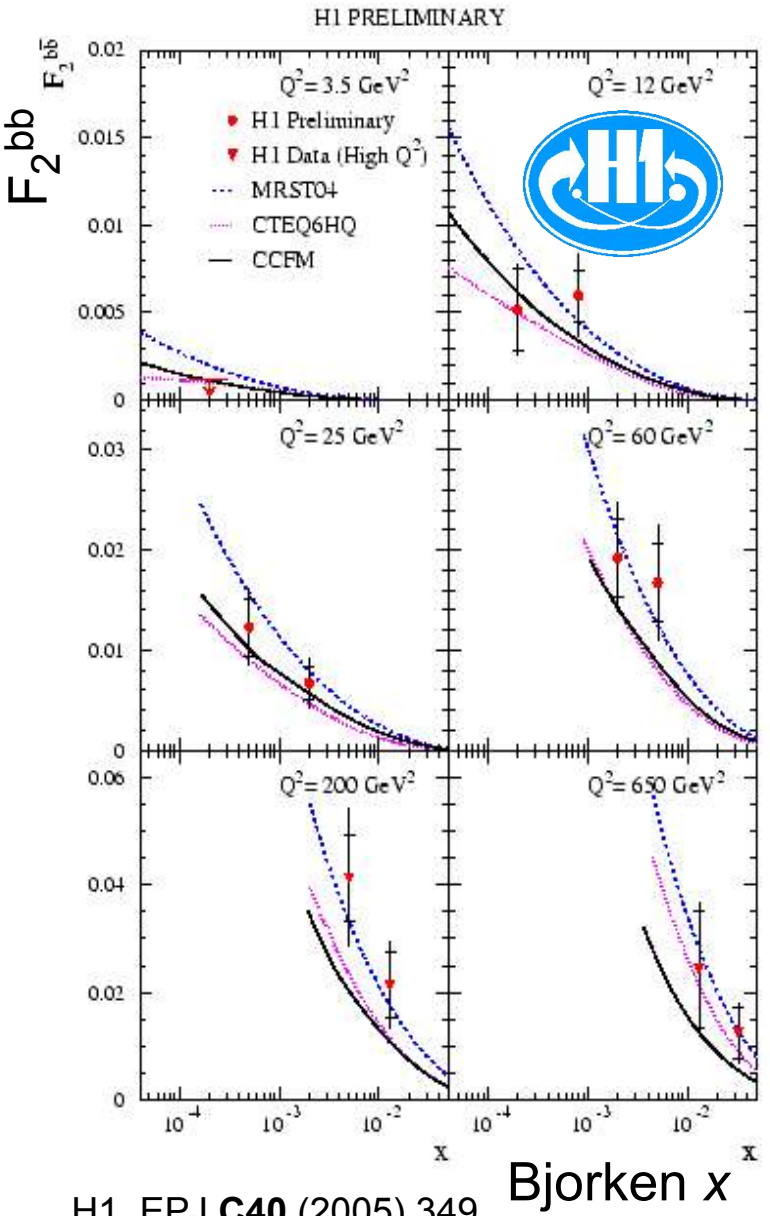
- Inclusive cross sections (F_2^{bb})
- Visible cross sections

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
- ZEUS: New Micro Vertex Detector allows the same technique

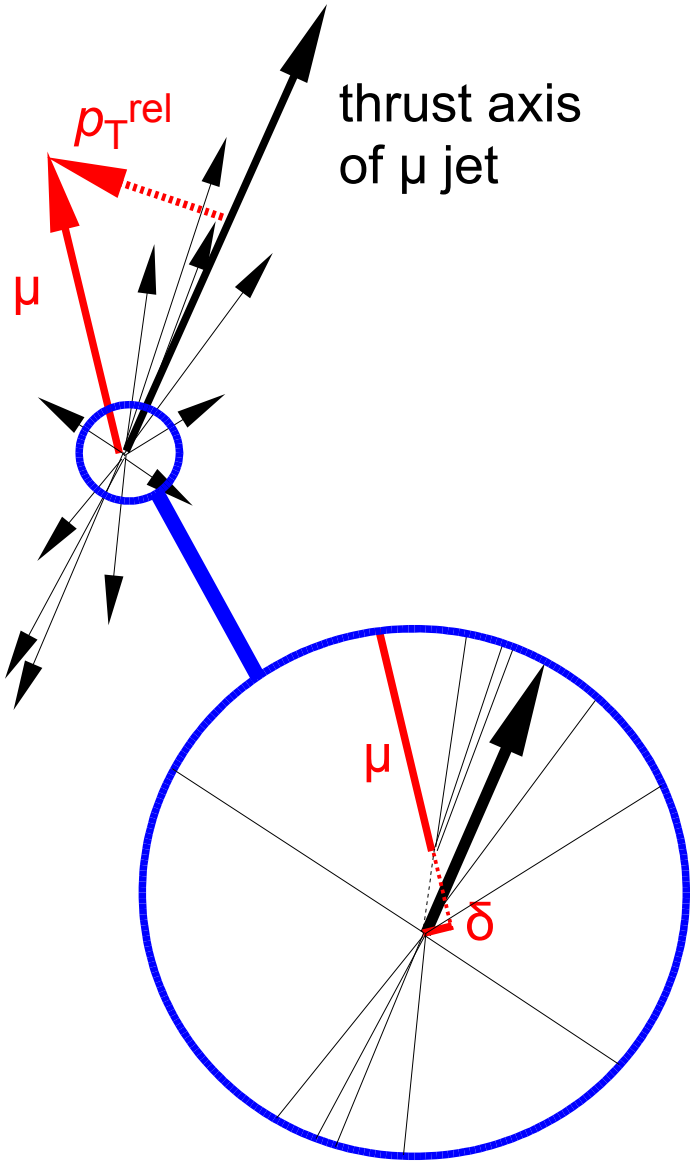


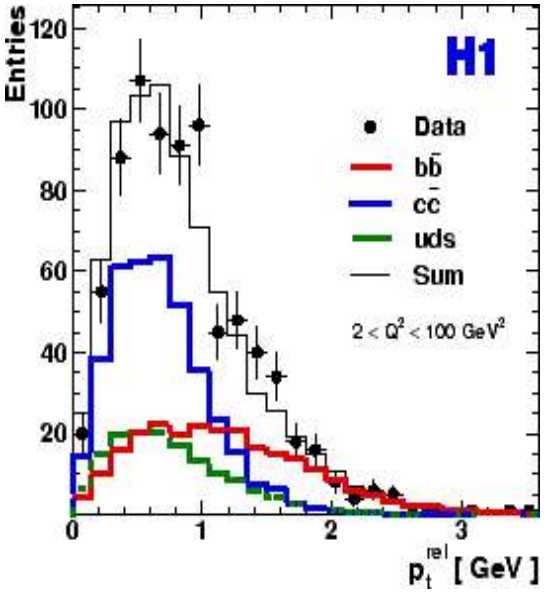
ZEUS preliminary 04-029

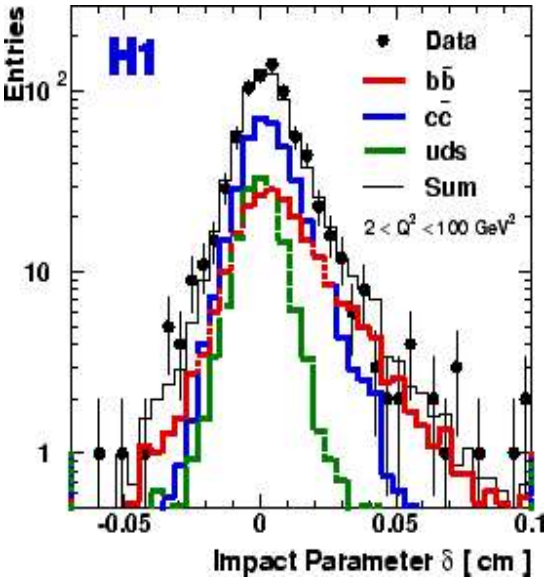


H1, EPJ **C40** (2005) 349.
H1 preliminary 05-076

Measuring Beauty Production with μ+jets





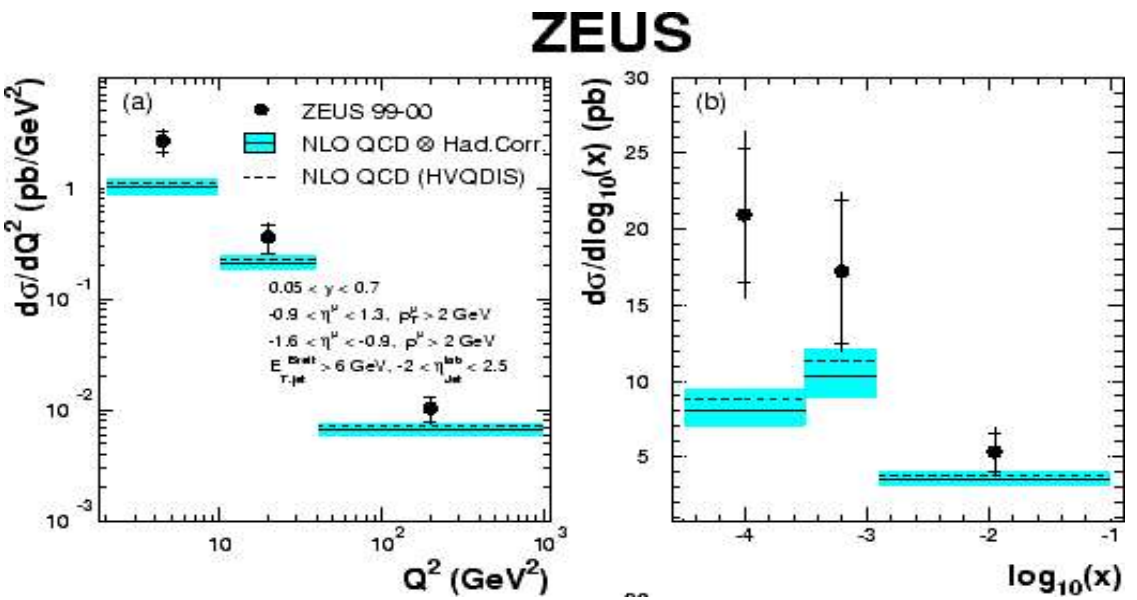


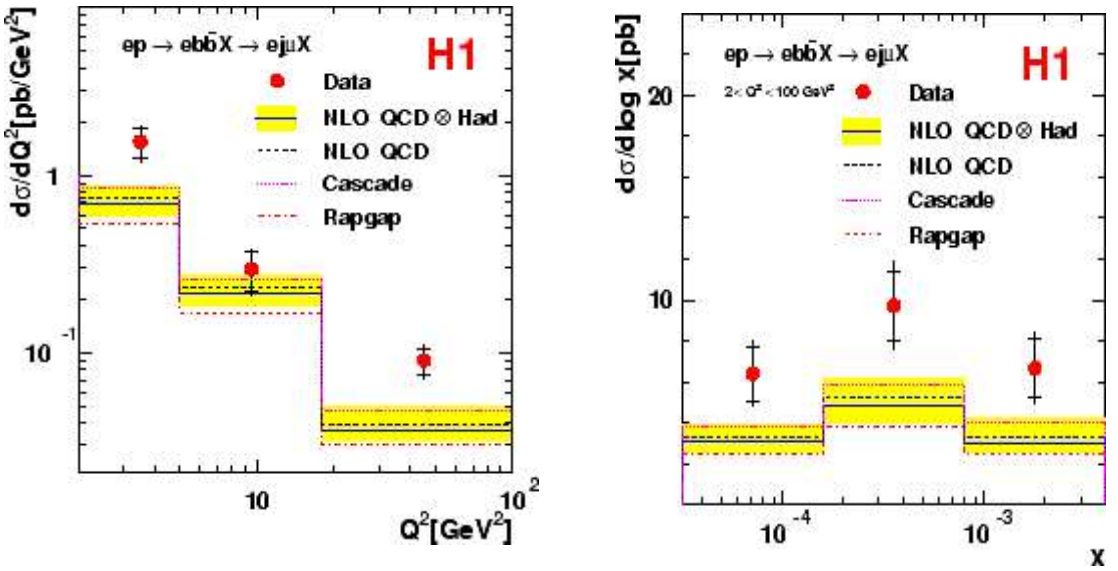
H1, hep-ex/050210

H1, hep-ex/050210

Visible Beauty Cross Sections

- Visible x-sections: More precise (less model dependant)
- 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 and $m_b{}^2$?

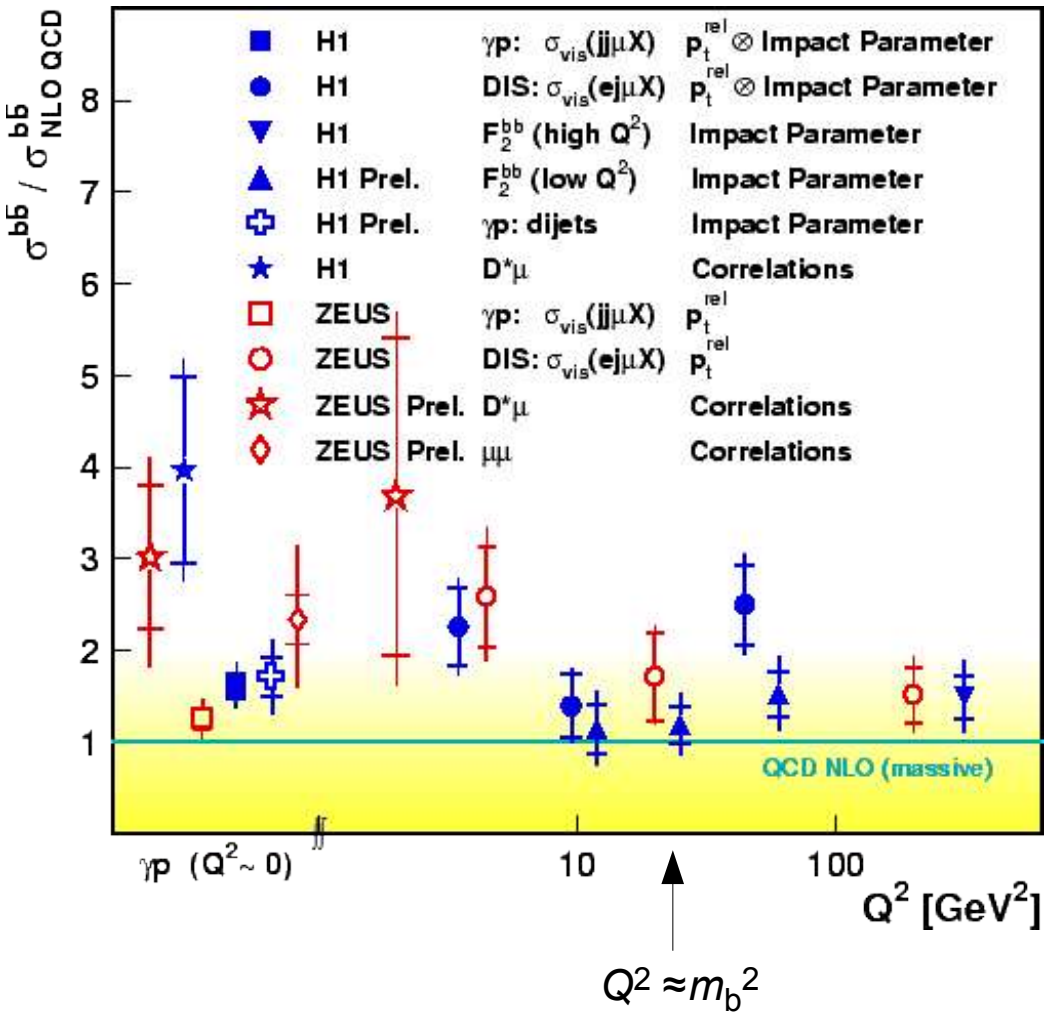




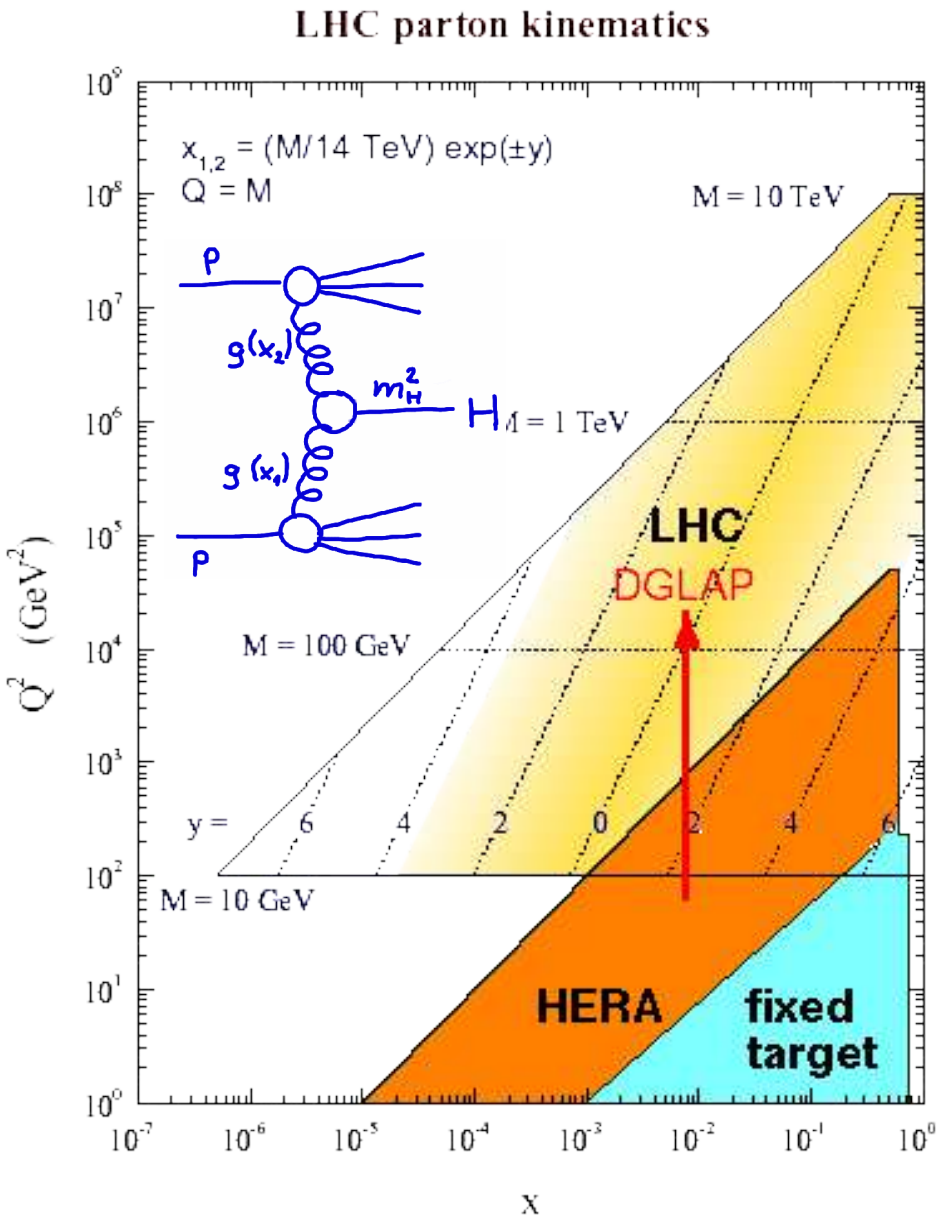
ZEUS, PL **B599** (2004) 173.H1, hep-ex/050210

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
  - take gluon k_t into account



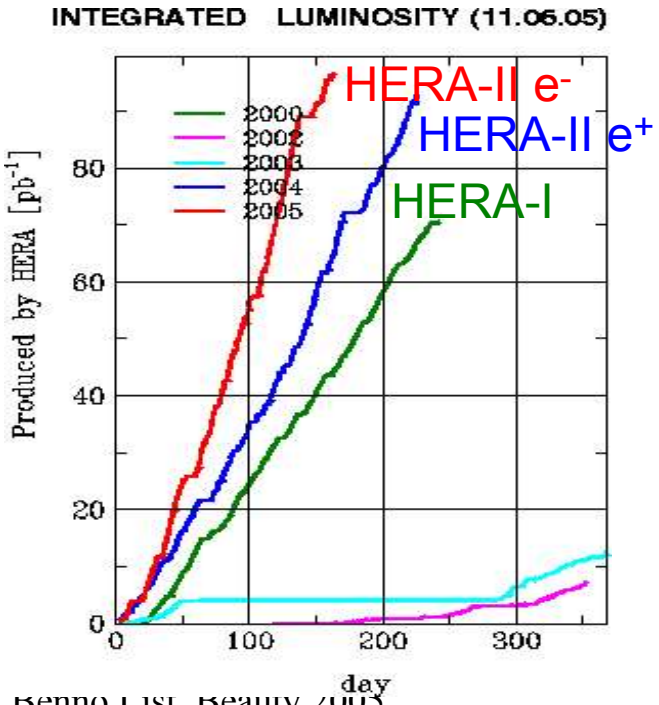
From HERA to LHC



- HERA provides precise parton densities needed by LHC for background and signal calculation
- HERA data pushes theory:
  - NNLO calculations
  - Evolution equations (at s_{hat}>350GeV, top is „light“!)
  - Unintegrated gluon densities

Conclusions and Outlook

- Charm production well described by NLO QCD
- Charm data precise enough to constrain the gluon at low Q^2
- Beauty production: a new field opening up
  - Jet+μ data higher than NLO expectation
  - Data from lifetime tagging agree better, not yet as precise
- More and more HERA-II data coming in: the future is bright!



Backup slides

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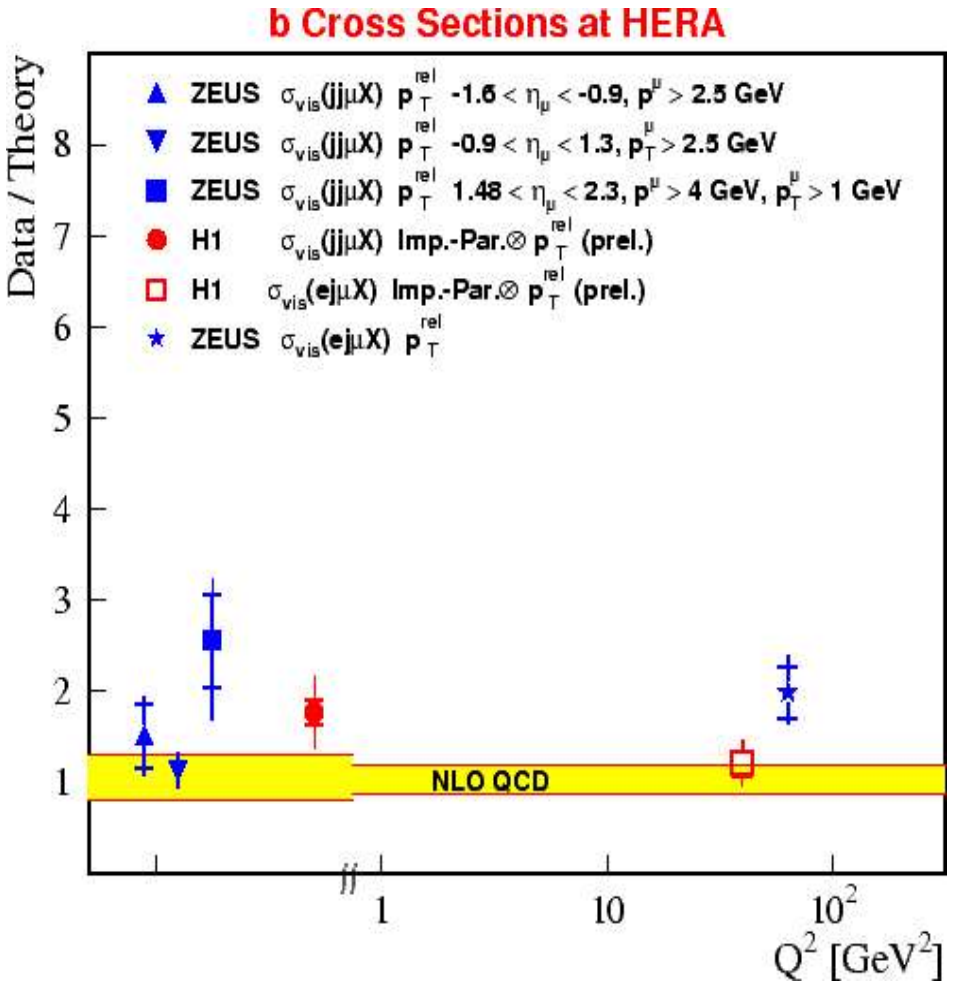
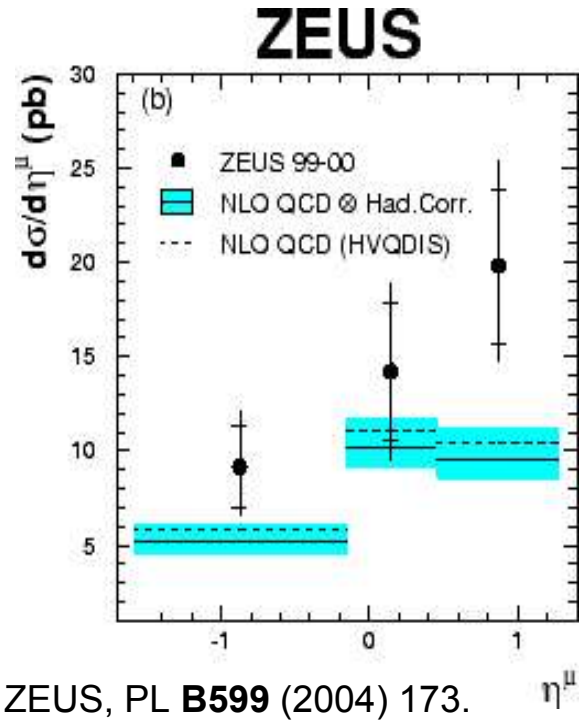


ZEUS, PL **B599** (2004) 173.

Rapity Distributions

- Both experiments observe excess in forward direction, i.e. in direction of the proton remnant



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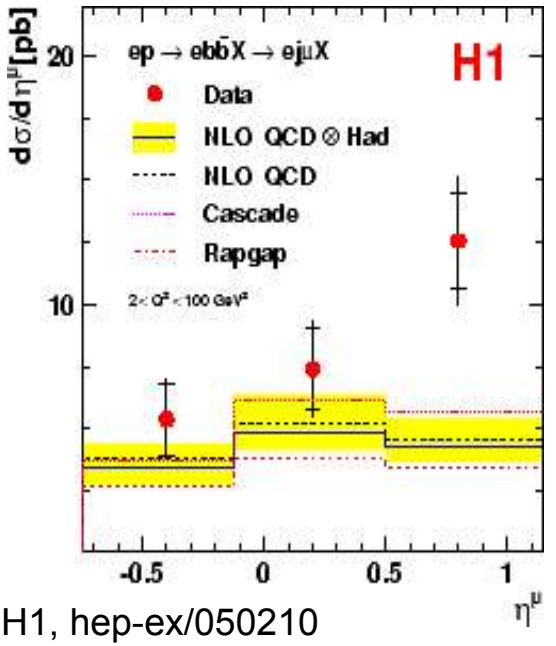
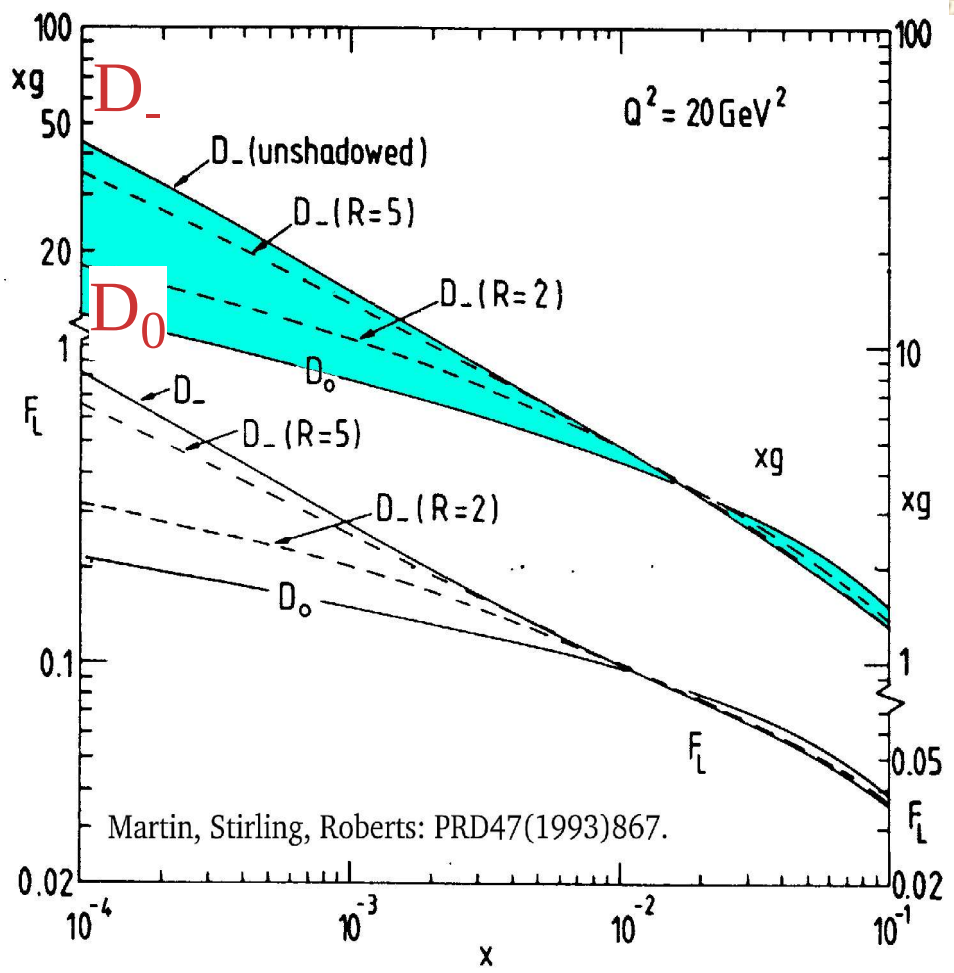


H1, hep-ex/050210

The Gluon at HERA



Pre-HERA status:
gluon **guess** uncertain by a factor 3 at Q^2=20GeV^2 and x=3·10^{-4} .

Today: gluon **known** to better than 10% at Q^2=20GeV^2 and x=3·10^{-4} from F_2 measurements