Review of Heavy Flavor Production in *ep* Collisions

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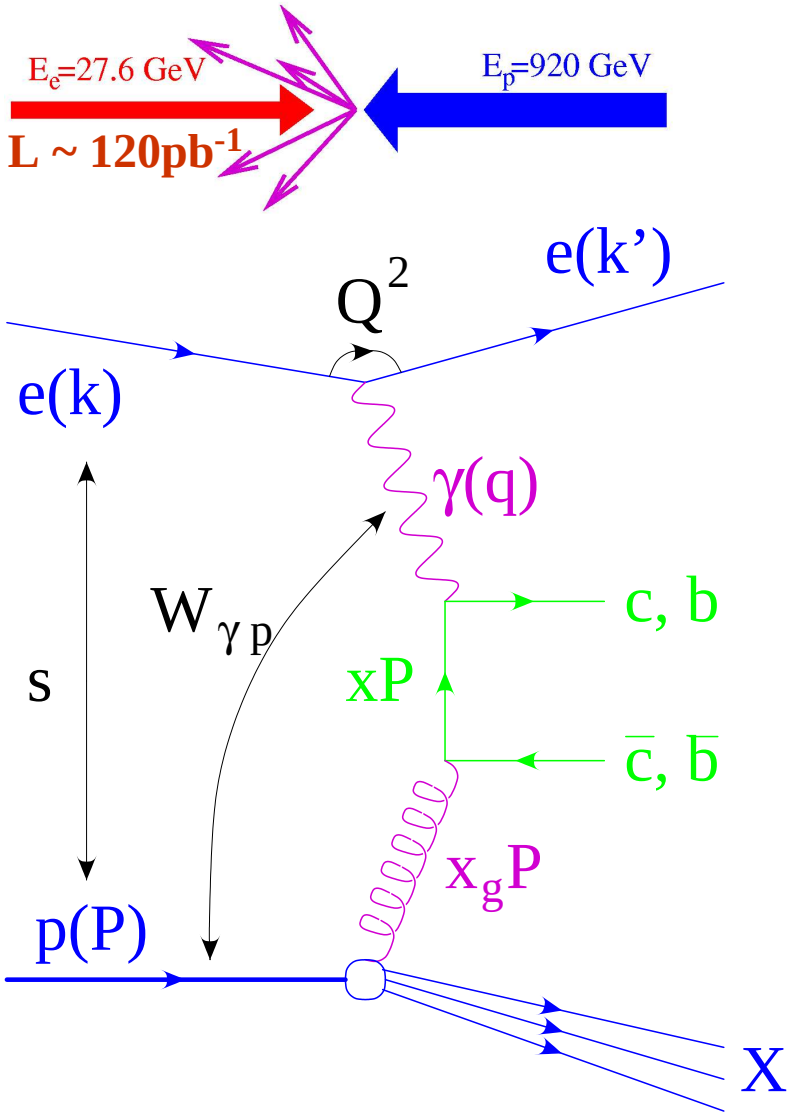
ISMD 2003

- **Heavy Flavor Models at HERA**
- **Charm Production**
- **Beauty Production**

Heavy Flavor Production



Boson-gluon fusion mechanism

Q^2: γ virtuality

x_g: parton fraction energy

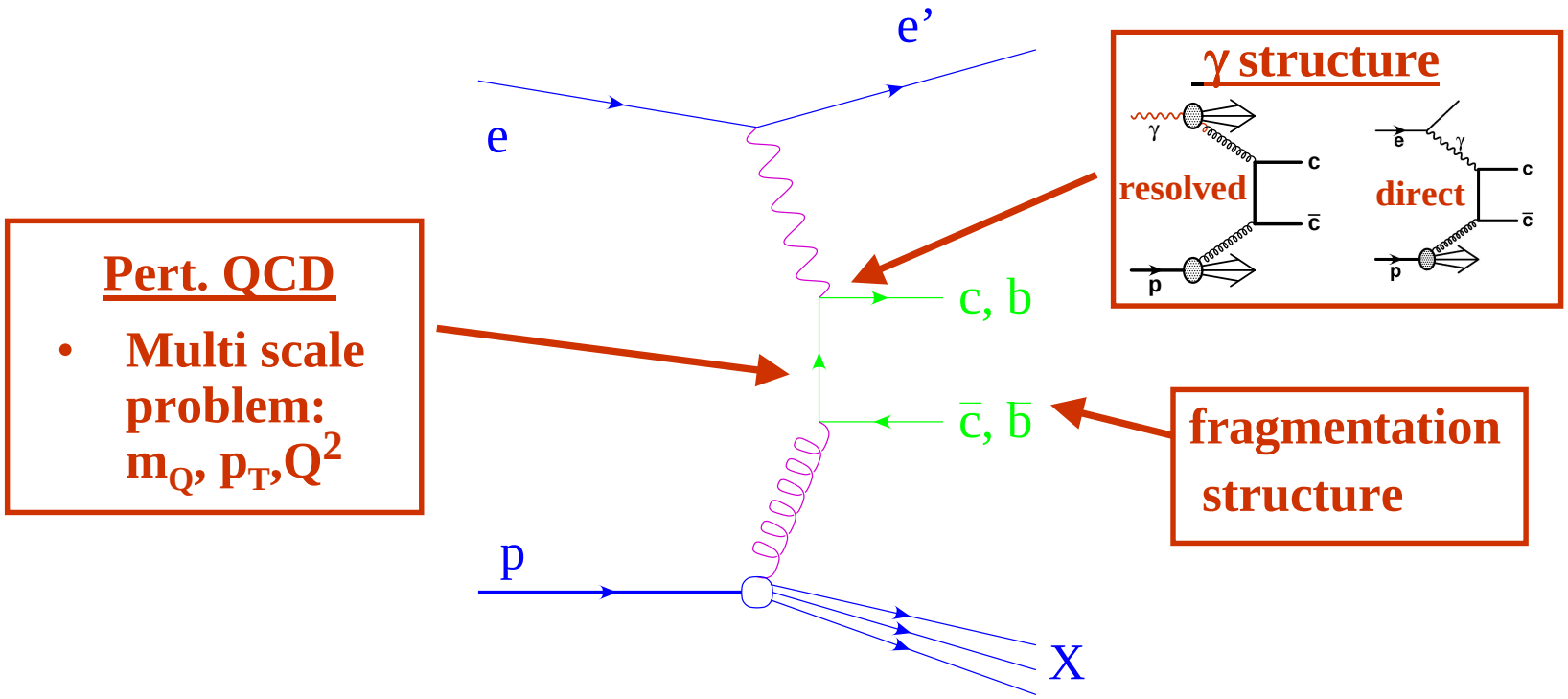
$W_{\gamma p}$: (γp) center of mass energy

Kinematic domains:

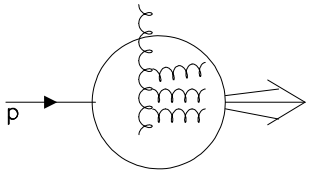
- $Q^2 < 1$ GeV^2: photoproduction
- $Q^2 > 1$ GeV^2: DIS (electroproduction)

Probing of QCD with Charm and Beauty

Factorisation: *p* structure ⊗ Pert. QCD ⊗ γ structure ⊗ fragmentation structure



***p* structure**



- **Partons density in *p***
- **Evolutions models: CCFM, DGLAP, BFKL (evolution in x, Q^2)**

Charm and Beauty Production Models

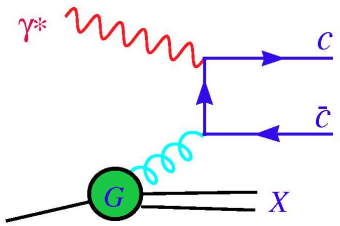
pQCD calculations in NLO: (DGLAP)

- **Massive scheme, fixed order:**

  $p_T \approx m_q$

  γp: FMNR (Frixione *et al.*)

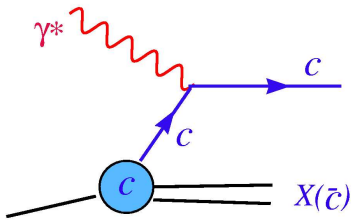
  DIS: HVQDIS (Harris&Smith)



- **Massless scheme, all orders (NLL):**

  $p_T >> m_q$ **. HQ in γ or *p***

  γp: Cacciari, Kniehl



- **Matched scheme: (FONLL)**

  Cacciari *et al.*)

MC generators (LO ME + PS):

- **DGLAP evolution:**

  AROMA: direct contribution only

  Pythia, Rapgap, Herwig:

  direct + resolved

- **CCFM evolution:**

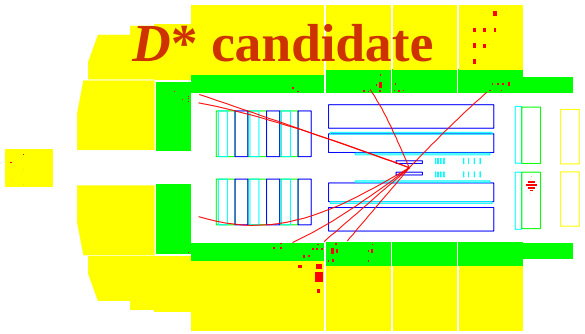
  CASCADE

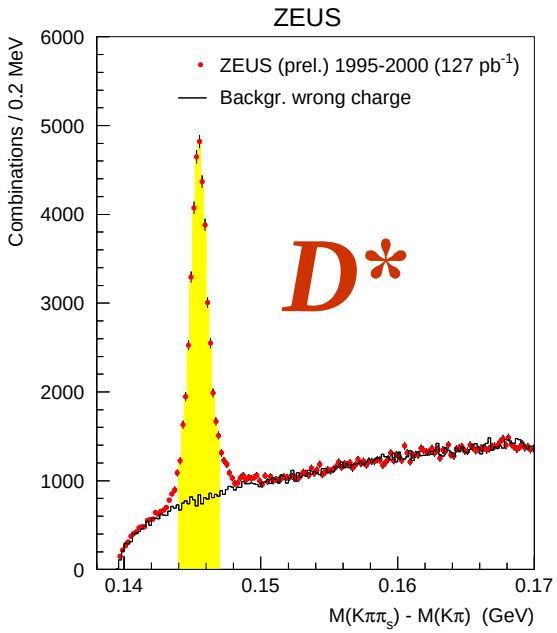
Theory vs Measurements

Q^2

m_Q

	Photoproduction $Q^2 \approx 0$	DIS $Q^2 > 1\ \mathrm{GeV}^2$
c	• Charm hadronization, fragmentation • Differential cross sections with D^* and D^*+jets	• $F_2^{c\bar{c}}$
b	• Cross sections with $B \rightarrow \mu X$, NLO comparisons	• Cross sections
	• Charm – Beauty correlations	



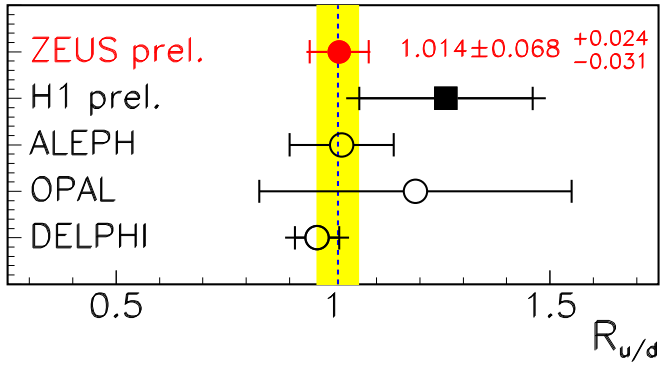


$R_{u/d}$, γ_s and P_V

- **QCD vacuum felt by *c* quark during hadronization:**

$$R_{u/d} = \frac{c\bar{u}}{c\bar{d}} = \frac{\sigma(D^{0,*0})}{\sigma(D^{\pm,*\pm})} = \frac{\sigma(D^0)}{\sigma(D^\pm)+\sigma(D^0)}$$

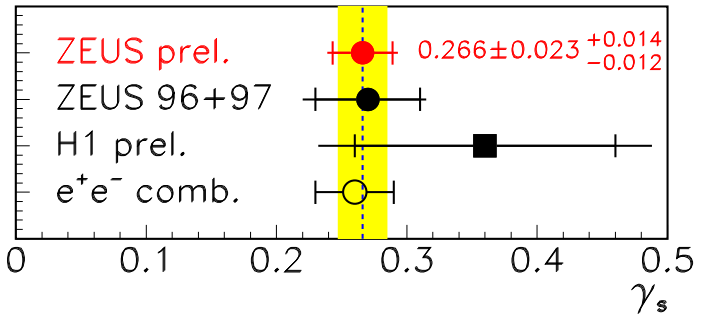
→ *equal number of u and d quarks (as seen by c)*



- **Strangeness seen in vaccum:**

$$\gamma_s = \frac{2c\bar{s}}{c\bar{d}+c\bar{u}} = \frac{2\sigma(D_s^\pm)}{\sigma(D^\pm)+\sigma(D^0)+2+\sigma(D^{*\pm})}$$

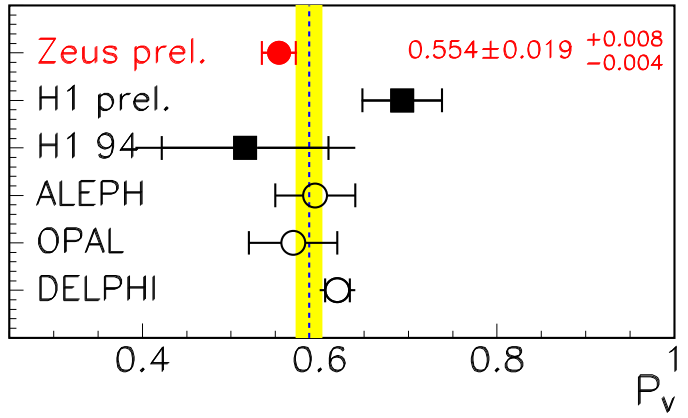
→ *s quarks suppressed by a factor of 4*



- **Vector vs pseudoscalar mesons, spin counting:**

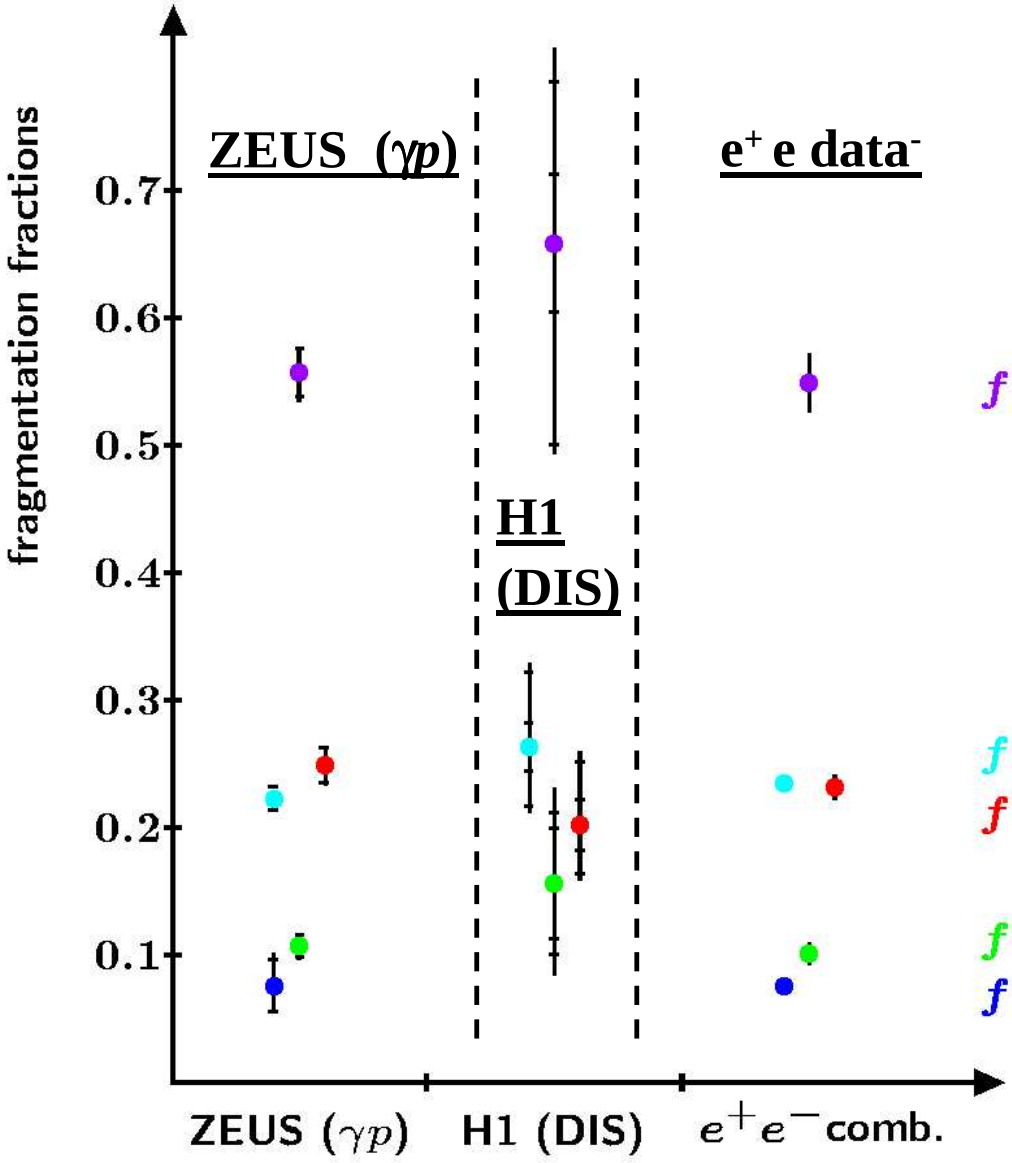
$$P_V = \frac{V}{V+P} = \frac{\sigma(D^*)}{\sigma(D^*)+\sigma(D)} \neq 3/4$$

→ *naïve spin counting does not work for charm*



Charm Fragmentation Fractions

Zeus: reconstruct all charm ground states, D^0, $D^{\pm}$, $D_s^{\pm}$, $\Lambda_c^{\pm}$ *and* $D^{*\pm}$



$f(c \to D^0)$

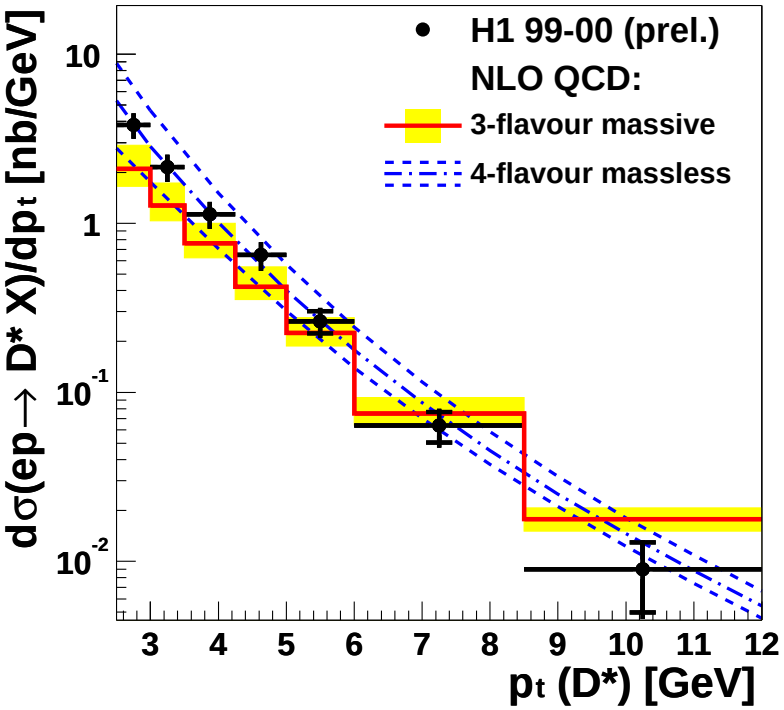
$f(c \to D^{*+})$
$f(c \to D^+)$

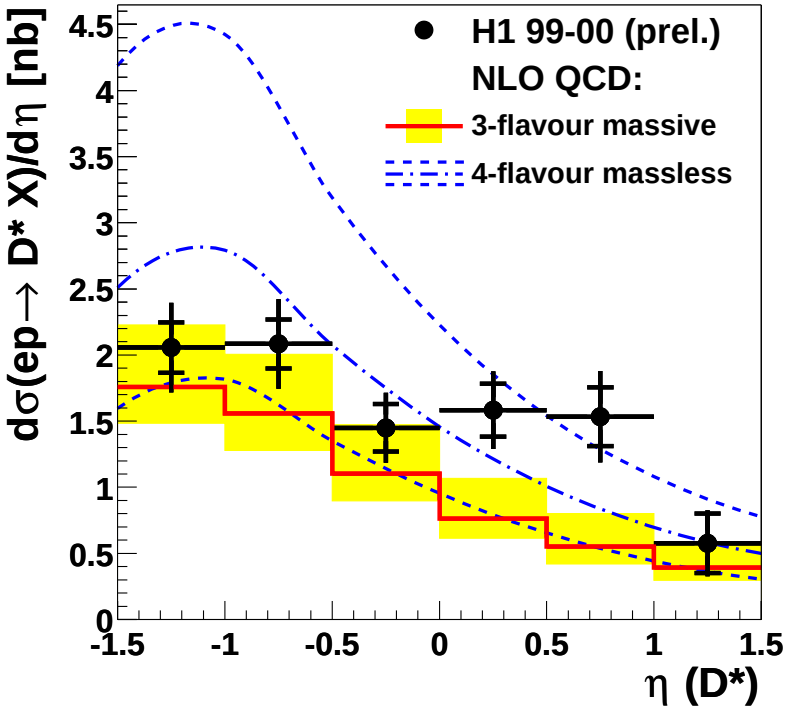
$f(c \to D_s^+)$
$f(c \to \Lambda_c)$

→ **charm fragmentation functions are universal**

*D** in Photoproduction

H1, inclusive *D:**



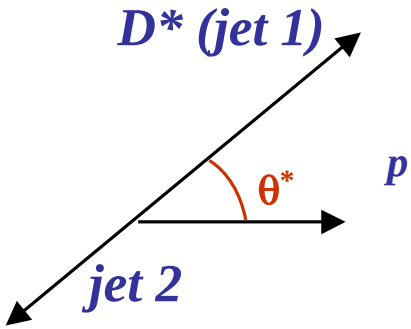


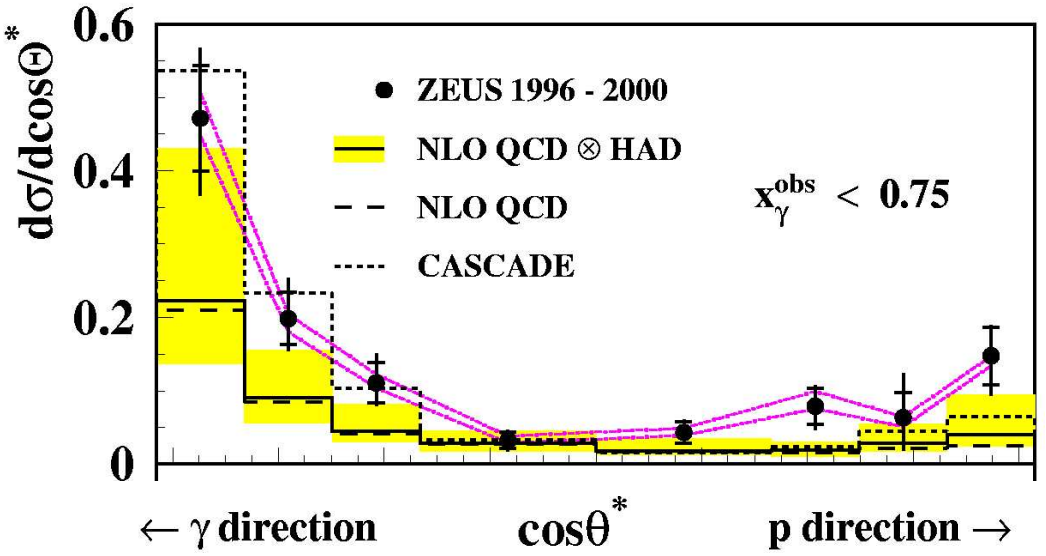
- **Massive NLO below data; Massless NLO in reasonable agreement**
- **Large theoretical uncertainties:**
  data let to constrain the models ↔ need more precise models!

*D** γ*p*: Dijet Angular Distributions

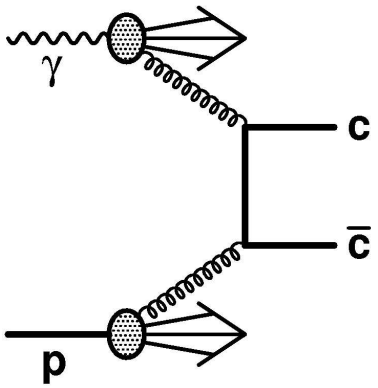
ZEUS, *D+2jets:**

jet-jet rest frame:

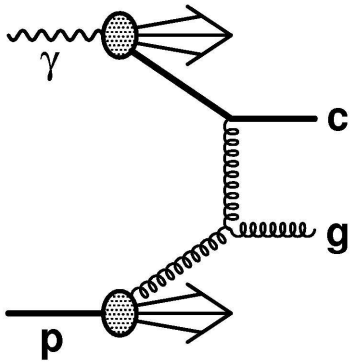




Photon resolved contribution:



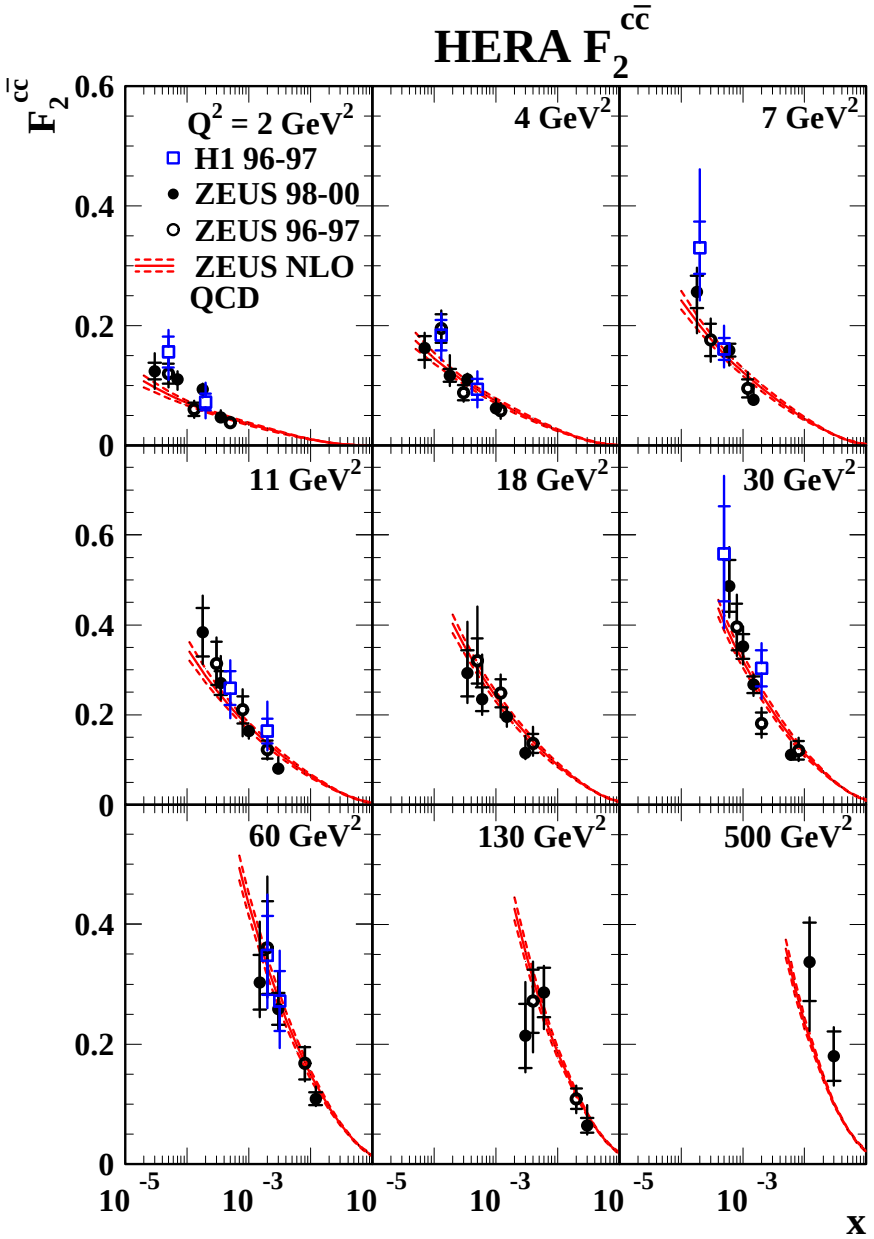
sym. in cosθ*



asym. in cosθ*

- **Significant resolved contribution (~40%)**
- **NLO DGLAP: OK for direct contribution, too low for resolved contribution**
- **CCFM (Cascade): reproduce shape, cross section too high**

D^* in DIS: $F_2^{c\bar{c}}$



$$\frac{d^2\sigma^{ep\to c\bar{c}X}}{dQ^2dx} = \frac{2\pi\alpha^2}{Q^4x}(1+(1-y)^2)F_2^{c\bar{c}}(x,Q^2)$$

- **Agreement between H1, ZEUS and NLO QCD fit over a wide range of x and Q^2**
- **Strong rise towards low x and high Q^2**

  $\rightarrow$ driven by gluon density in proton

Charm Summary

Charm hadronization and fragmentation:

- independent of the hard process (ep, e^+e^-)

Charm in γp:

- Large charm content in the photon
- NLO calculations ~OK, but do not describe all aspects of data
- Large theoretical uncertainties, existing data constrain models

Charm in DIS:

- F_2^{cc}: nice H1 / ZEUS / NLO fit agreement

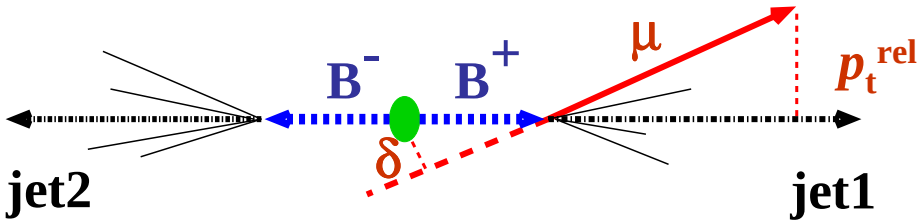
Beauty Tagging

$\sigma(bb) / \sigma(cc) \sim 10^{-2}$

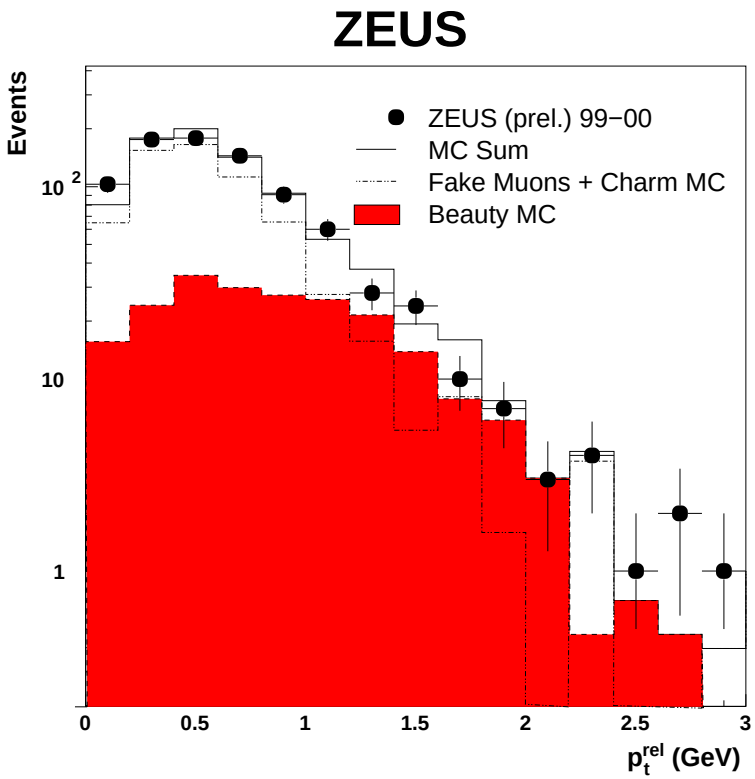
→ need specific *b* tagging methods

Use semileptonic b → μ decays

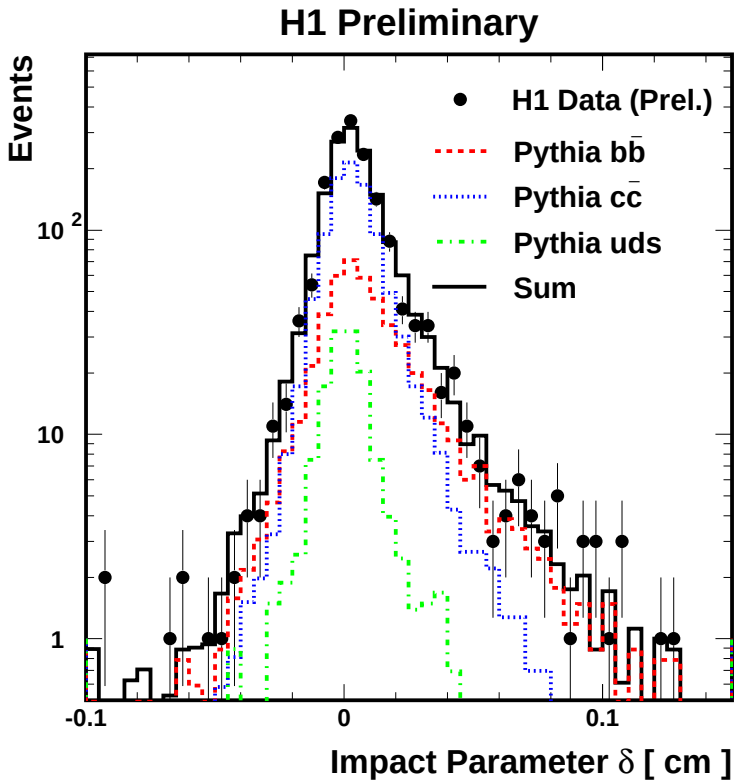
→ 2 methods



High B mass → p_t^{rel}

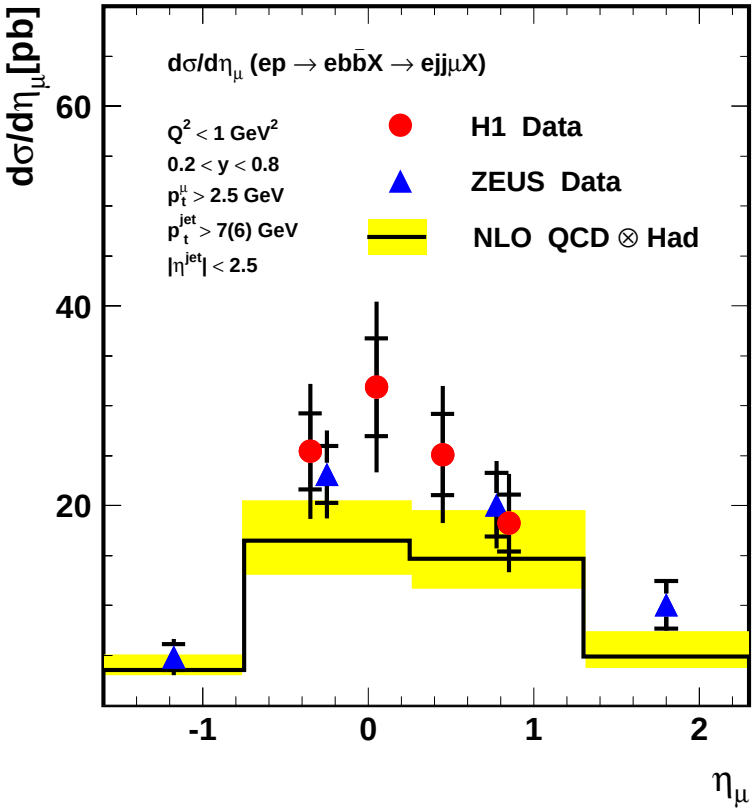


Long B decay → impact parameter δ

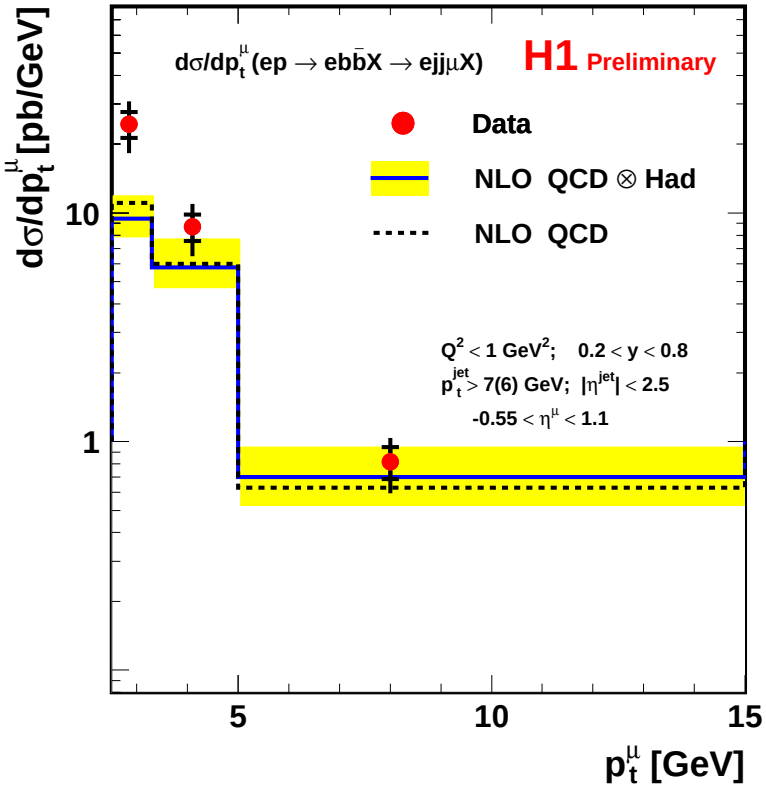


Beauty in photoproduction

H1, ZEUS: η_μ (NLO)

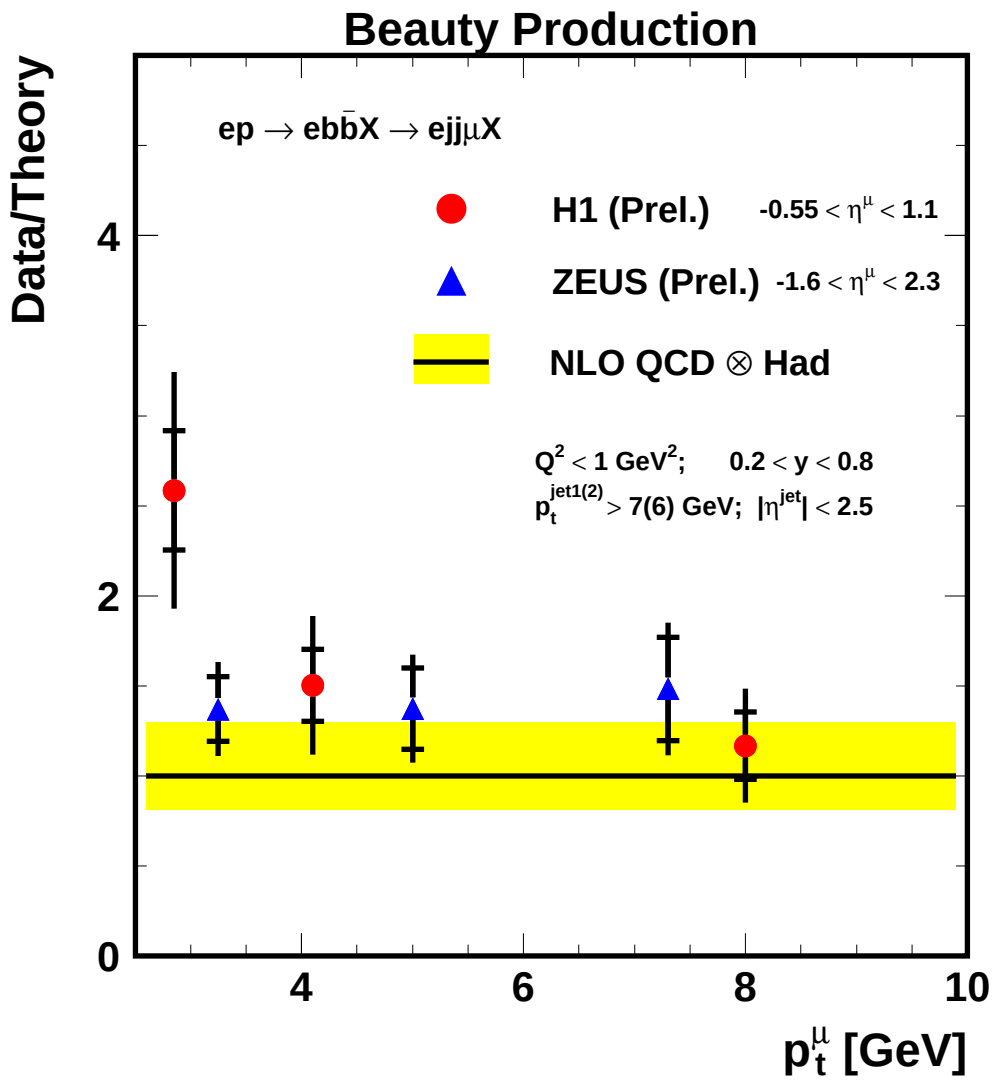


H1: p_t^μ (NLO)



- **Agreement between H1 and ZEUS**
- **NLO: OK at high p_T (too low at low p_t ?)**

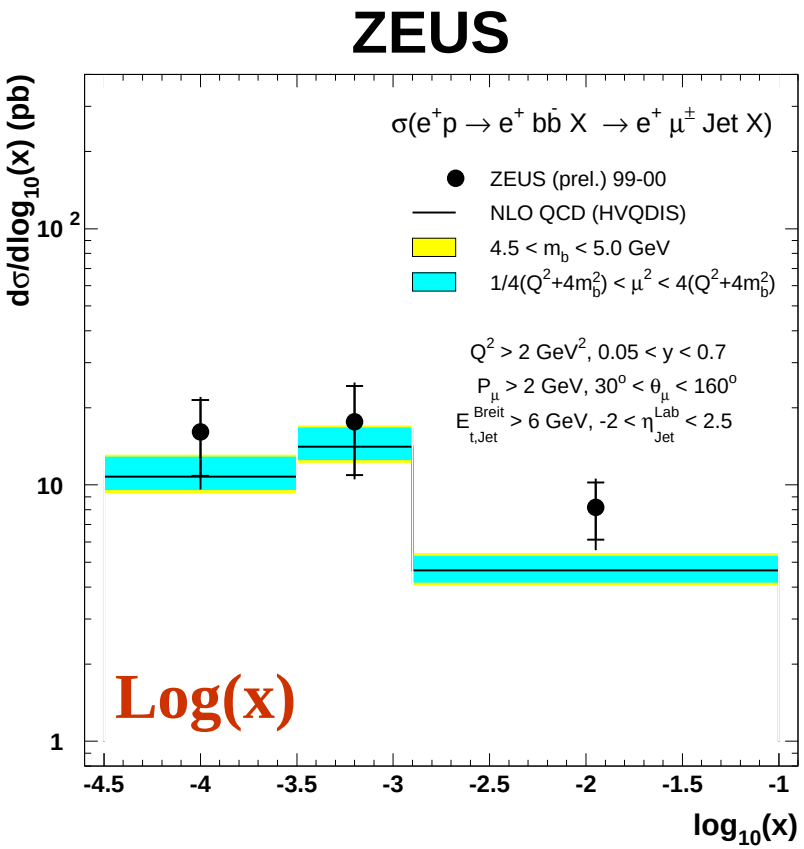
Beauty: data/theory

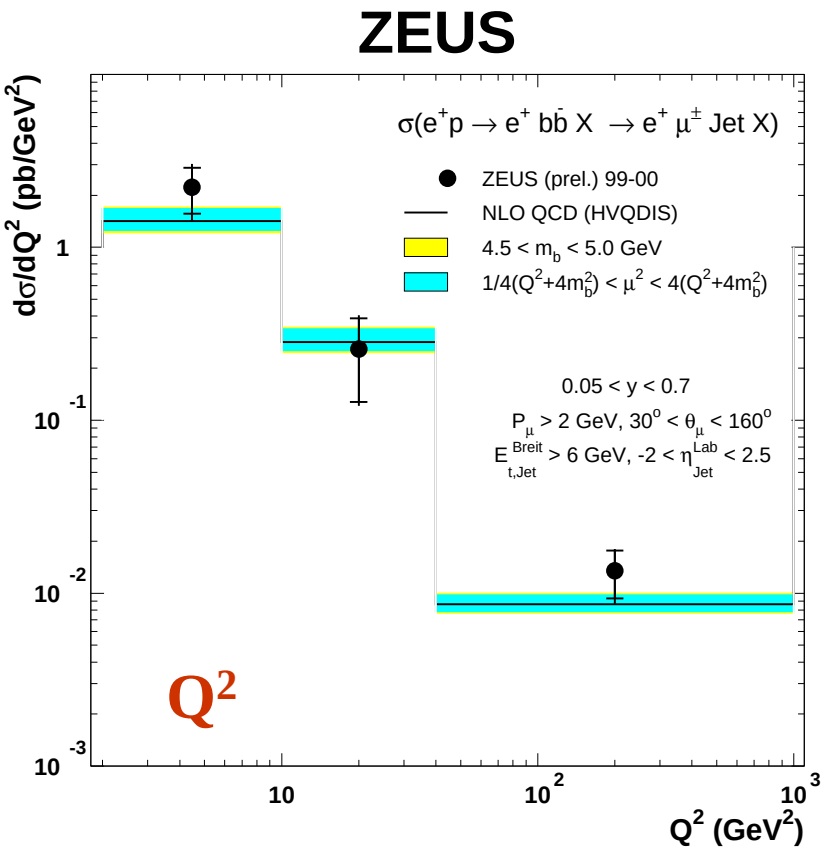


- **All data points above NLO QCD, but in agreement within errors**

Beauty in DIS

ZEUS: $Q^2 > 2\,\mathrm{GeV}^2$

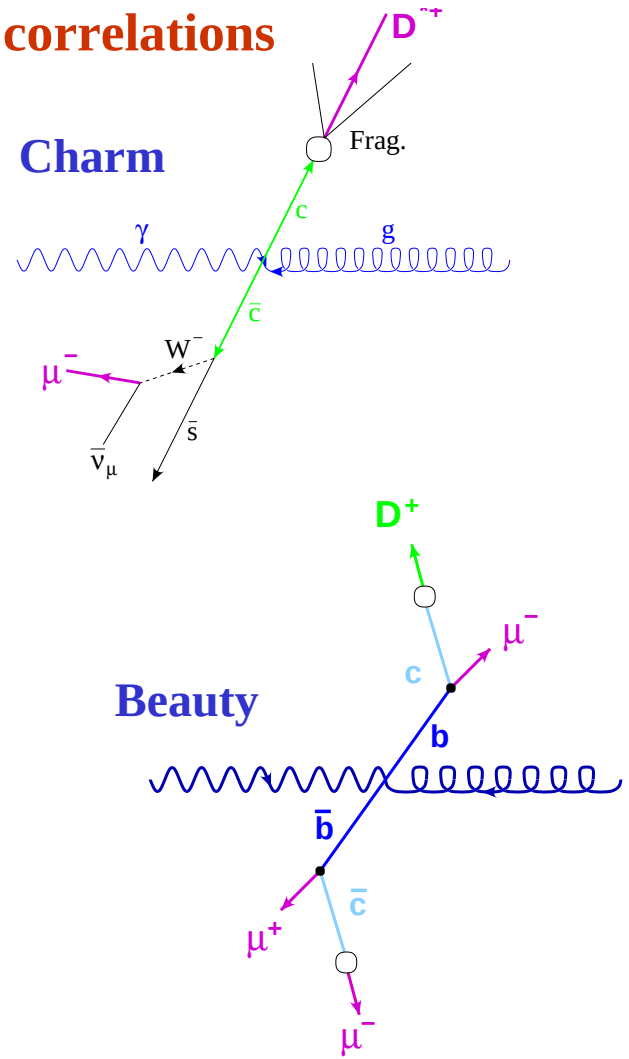




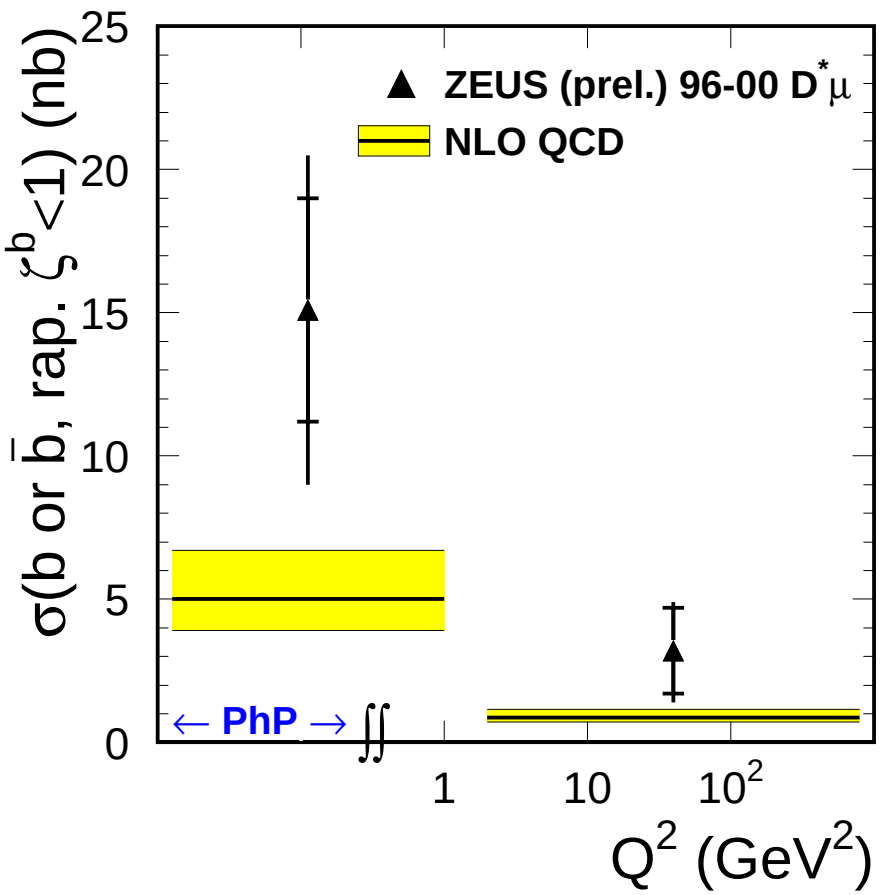
- **Data and NLO in agreement within errors**

Double *b* tagging: *D**μ correlations

***c-b* separation using charge and angular correlations**



Beauty cross section:



- **Data above NLO QCD, but large experimental errors**

Conclusions / Outlook

Charm:

- **γp : Massive scheme too low, massless DGLAP NLO ~OK**
- **DIS: Massive DGLAP NLO ~OK**
- **CCFM: promising, but do not describe all aspects of data**

Beauty:

- **γp and DIS: new results quite close to NLO (but still too high)**

Theoretical expectations for *c* and *b* still have large errors

HERA II:

- **Upgraded detectors, more luminosity**
- **New kinematic regions accessible in the forward direction**