Heavy Flavors and QCD (at Hera)

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on behalf of
the H1 and ZEUS collaborations
at Rencontres de Moriond 2000

Content: Open charm and beauty production in ep collisions:

New and recent experimental results

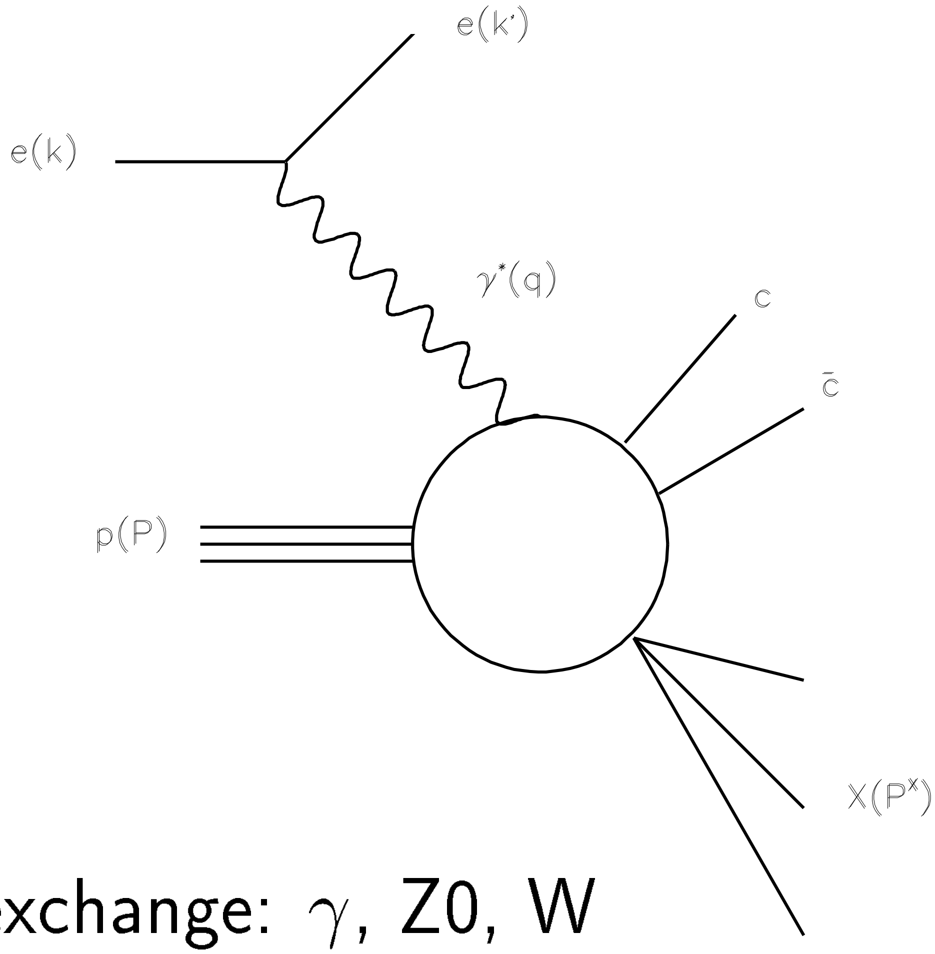
versus

QCD based predictions

Hera-kinematics

820 GeV $p \rightarrow$ • $\leftarrow$ 27 GeV e

$$\sqrt{s} = 300 \text{ GeV}$$



Boson exchange: γ, Z0, W

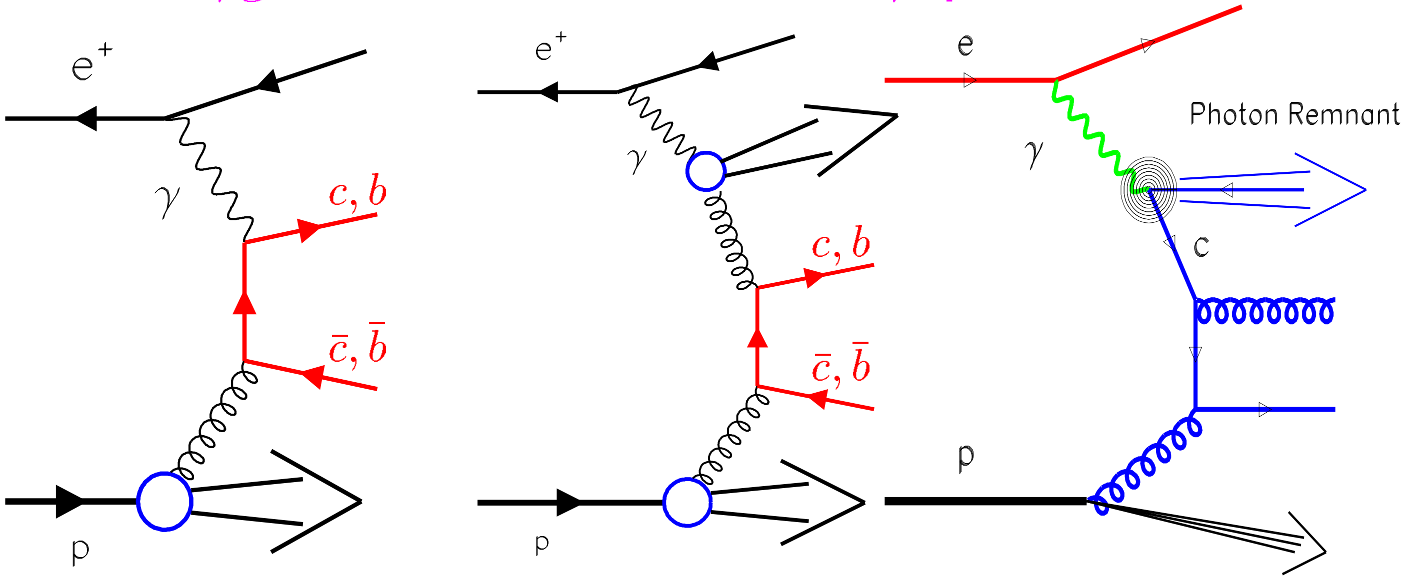
$$Q^2 = -q^2 = -(k - k')^2 \quad \leftrightarrow \quad \text{Virtuality}$$

$$y = \frac{P \cdot q}{P \cdot k} \quad \leftrightarrow \quad \text{Inelasticity}$$

$$x = \frac{Q^2}{2P \cdot q} = \frac{s}{Q^2 y}, \quad W = (P + q)^2$$

c,b production at HERA in LO QCD

Direct γg fusion   Resolved γ processes



- Sensitive to gluon density in proton
- Large masses of c and b provide hard scale $\Rightarrow$ pQCD becomes applicable and testable also at $Q^2 \approx 0$
- Resolved γ contributions:
  - Suppressed with Q^2
  - Sensitive to gluon and quark densities in photons

NLO pQCD Calculations

- Fixed order approach ("massive"):

  (Frixione et al.)

  – Only u,d,s active flavors in proton.
  – Charm and Beauty dynamically produced in BGF.
  – Should be valid at $P_T \approx m_Q$

- Resummed approach ("massless"):

  (Kniehl et al., Cacciari et al.)

  – u,d,s,c,b are active flavors in p and γ
  – Resummation of $[\alpha_s \, log(\frac{P_T}{m_Q})]^n$ terms
  – Should be valid at $P_T > m_Q$

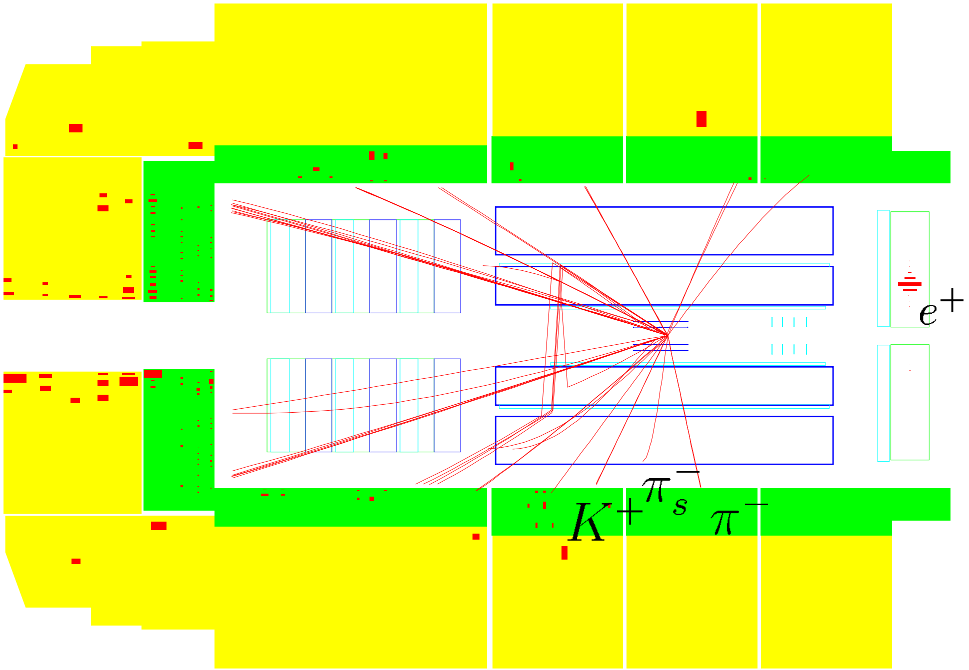
Theory confronted with measurements

Menu for today:

$Q^2 \rightarrow$ $m_Q \downarrow$	Photoproduction $Q^2 \approx 0$	DIS $Q^2 \geq 1GeV$
c	Differential cross sections with D^*, new D_s	$F_2^{c\bar{c}}$, gluon density in proton with D^*
b	Cross section measurements with $B \rightarrow \mu X$ $B \rightarrow eX$ new: μ (ZEUS) new: NLO comparisons	$F_2^{b\bar{b}}$ ≥ 2001 upgrade

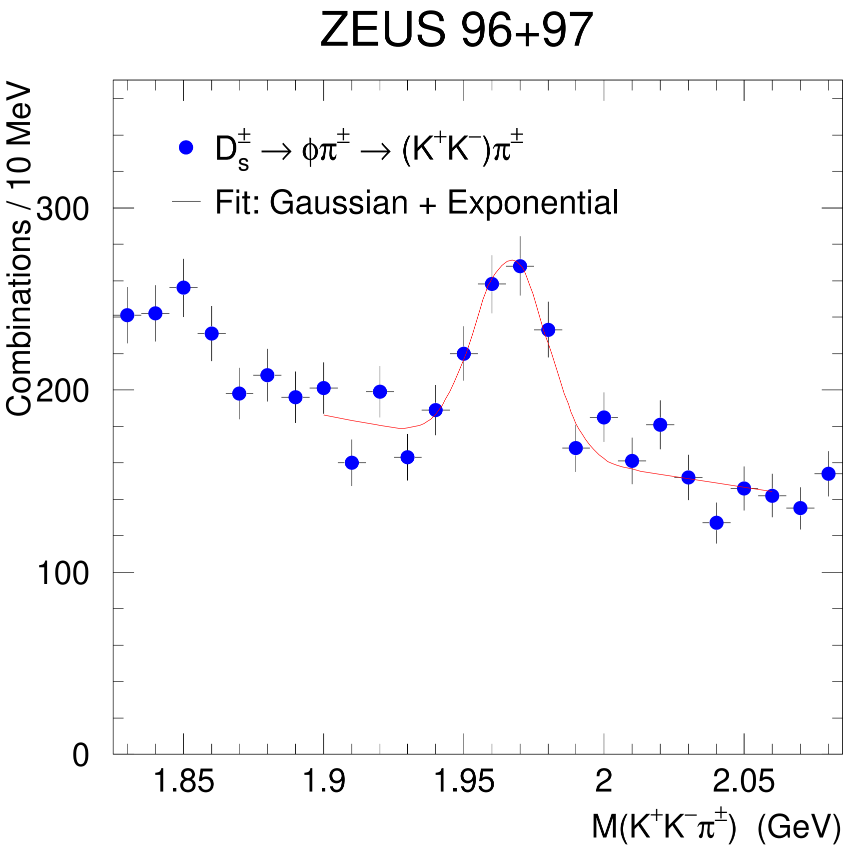
Charm tagging

- Use channels $D^* \to D^0\pi_s,\ D^0 \to K\pi, K\pi\pi\pi$



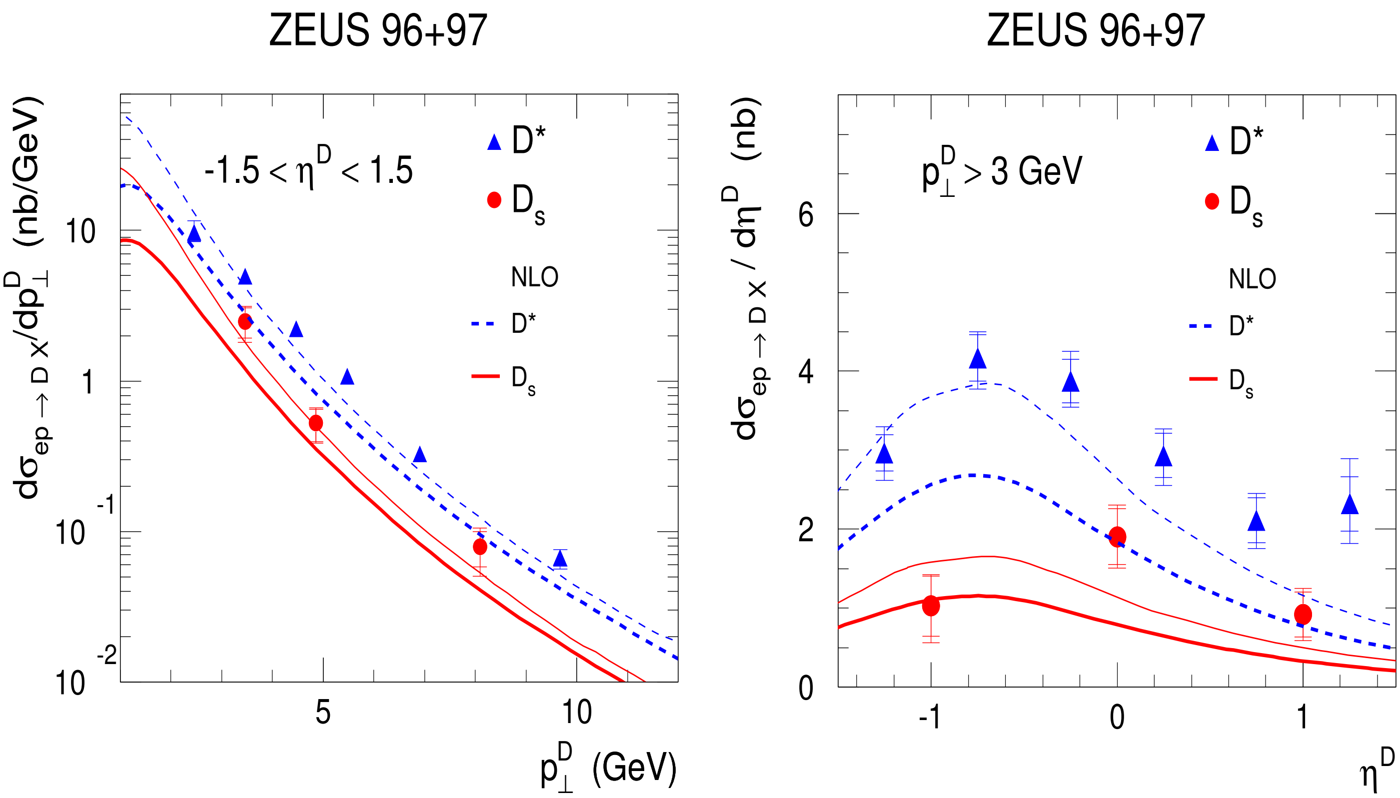
H1 $D*$ candidate
$Q^2 = 30\, GeV^2$

- Extract signal from $m(D^*) - m(D^0)$ distribution
- New! ZEUS uses $D_s \to \Phi\pi \to KK\pi$



D^*, D_S photoproduction results

- Compared with NLO QCD ("massive" scheme)



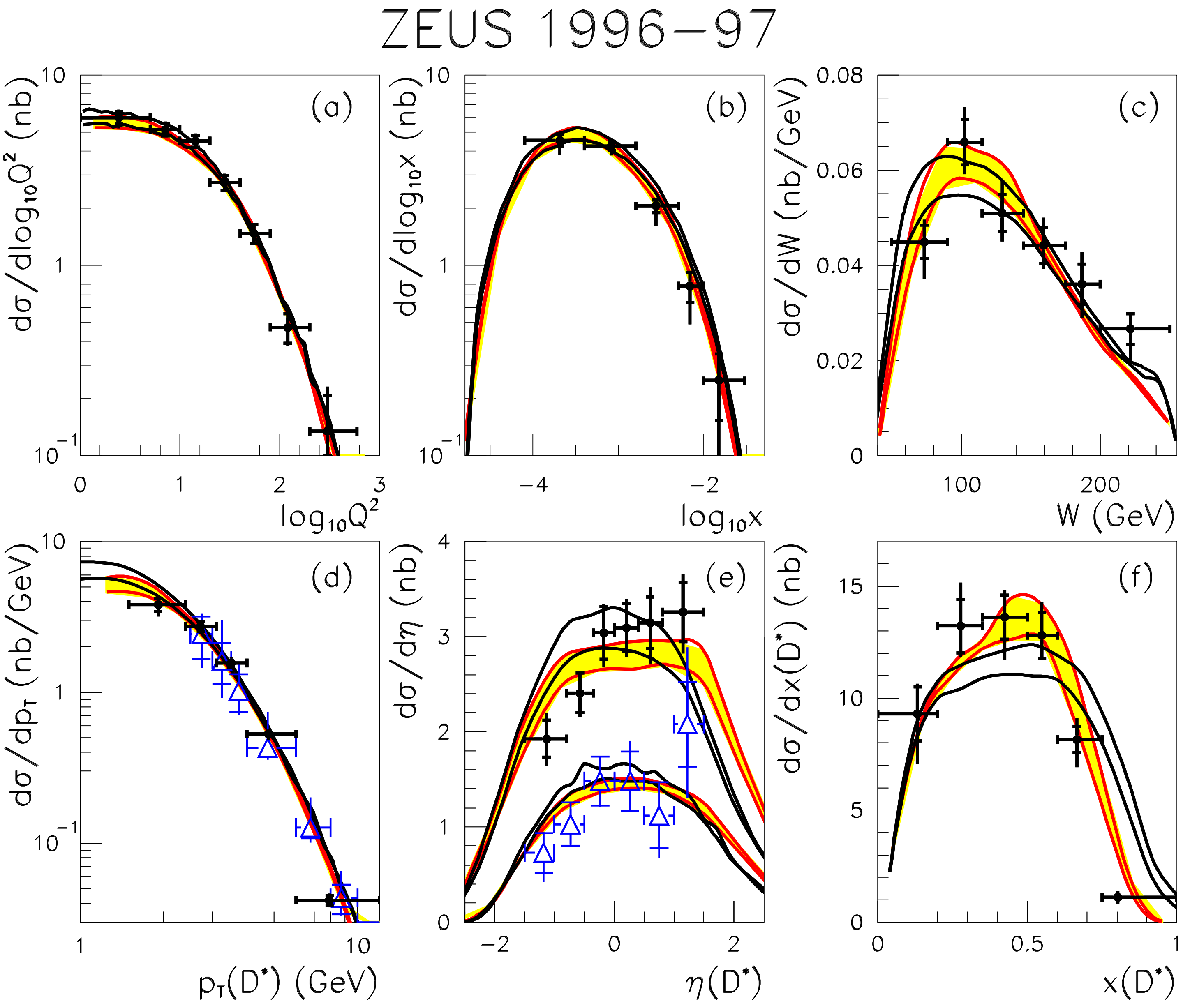
- Excesses of D^* and D_s data over "massive" NLO
- Predictions of massless theory for D^* come closer to the data (not shown here)
- New D_s results allow to test fragmentation:

Data		$\sigma(D_s)/\sigma(D^*)$	γ_s
HERA	ep	$0.41 \pm 0.07^{+0.03}_{-0.05}$	0.27 ± 0.05
LEP	e^+e^-	0.43 ± 0.04	0.26 ± 0.03

$\Rightarrow$ Universality of charm fragmentation!

D^* production in DIS

- Compare to NLO calculation (3 Flavors, "massive", B. Harris & J. Smith)
- Use two different fragmentations: Peterson function (open), Jetset-MC, (shaded)

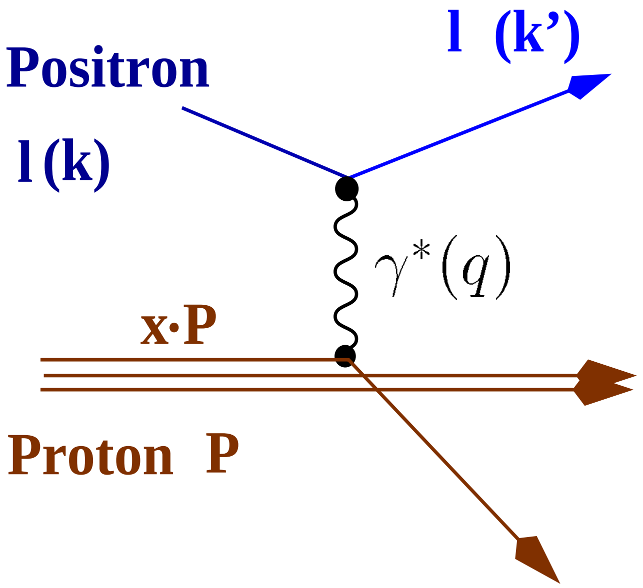


- good description by NLO
- $\eta(D^*)$ distribution sensitive to fragmentation

Charm contribution to DIS $\rightarrow F_2^{c\bar{c}}$

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

QPM model:



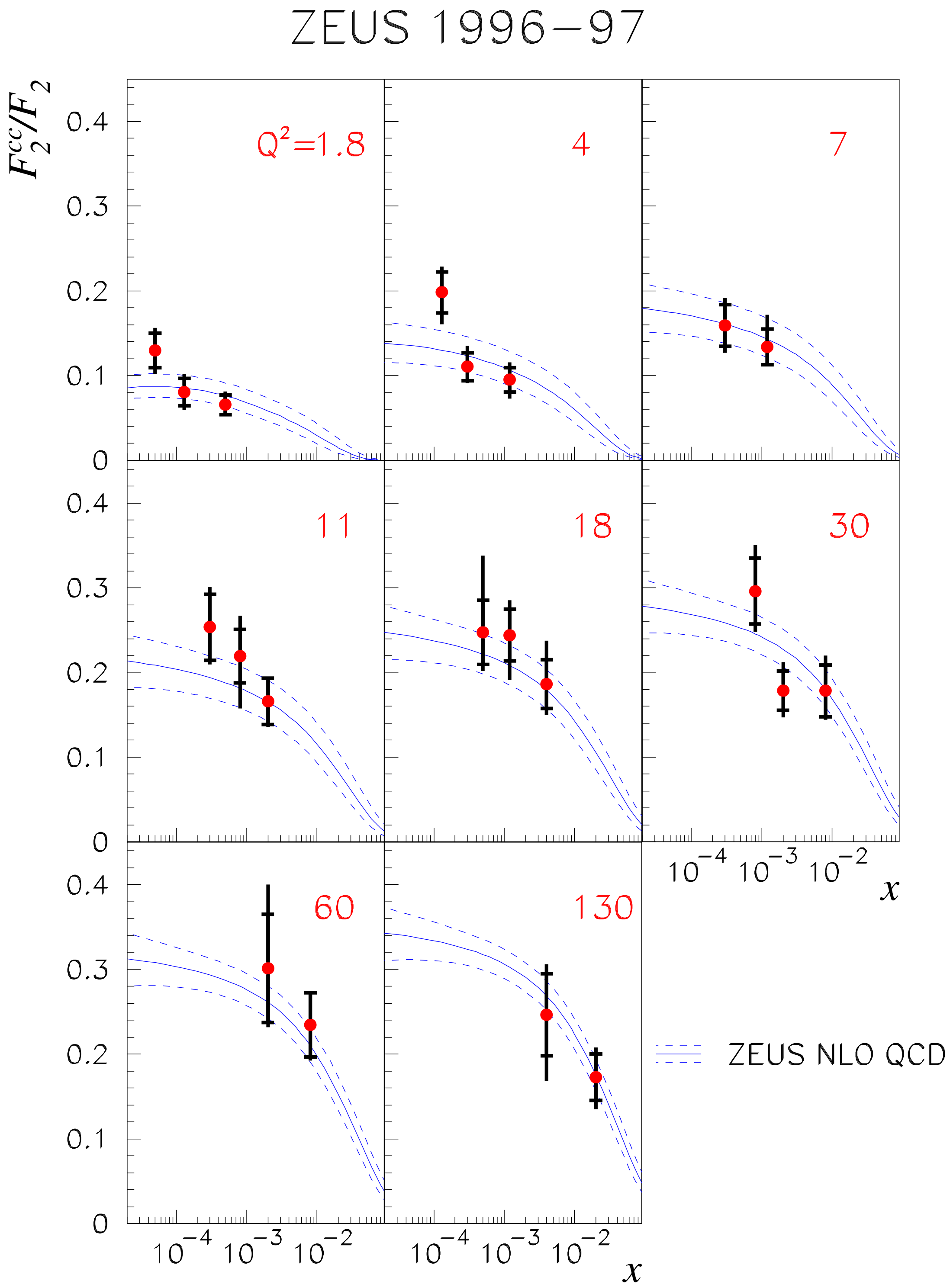
$$F_2 = \sum_i e_i^2 (q_i(x) + \bar{q}_i(x))$$

- QPM generally applicable only for light quarks, heavy flavors produced by BGF! $\rightarrow$ generic definition of $F_2^{c\bar{c}}$:

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

- To determine $F_2^{c\bar{c}}$ extrapolate D^* measurements to full $P_T(D^*)$,$\eta(D^*)$ phase space

$F_2^{c\bar{c}}/F_2$ results



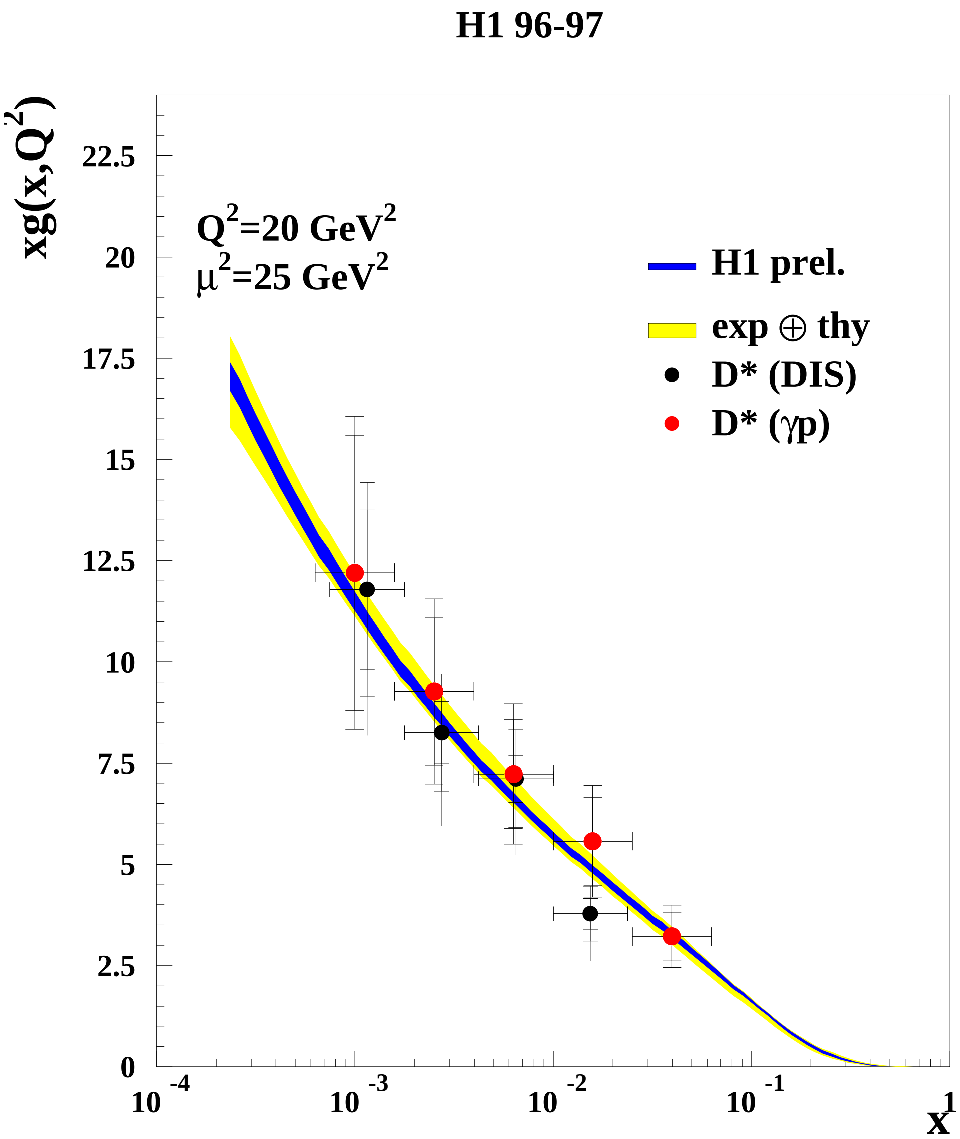
⇒ Good agreement with NLO

⇒ Large charm contribution at low x and high Q^2

↪ reflecting gluon content in proton

Direct measurement of gluon density

- Reconstruct gluon momentum from D^* and scattered e
- Iterative unfolding of gluon density by comparison with QCD calculations



$\Rightarrow$ Good agreement with gluon density from F2 (bands) $\Rightarrow$ universal gluon distribution

Open beauty photoproduction

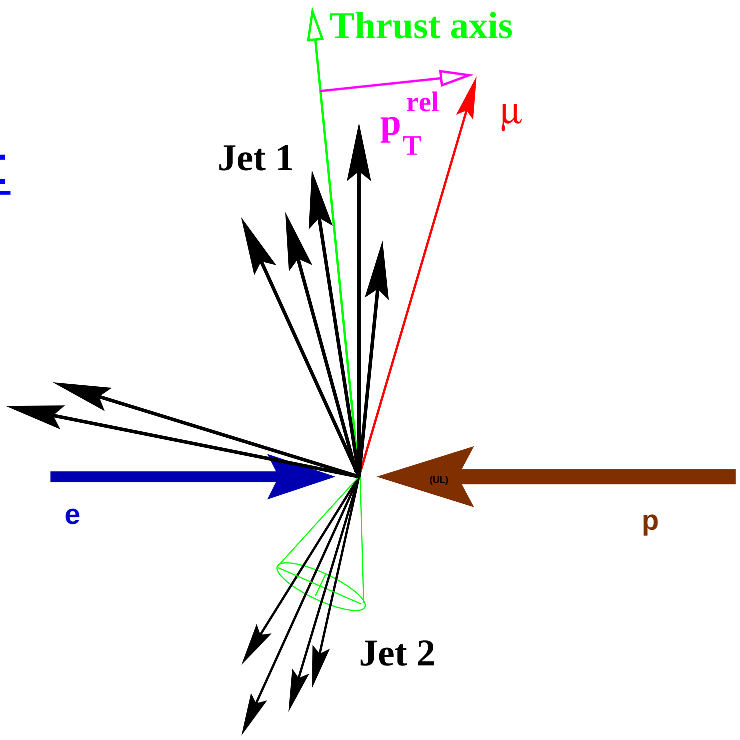
- Theory predicts low beauty cross sections:

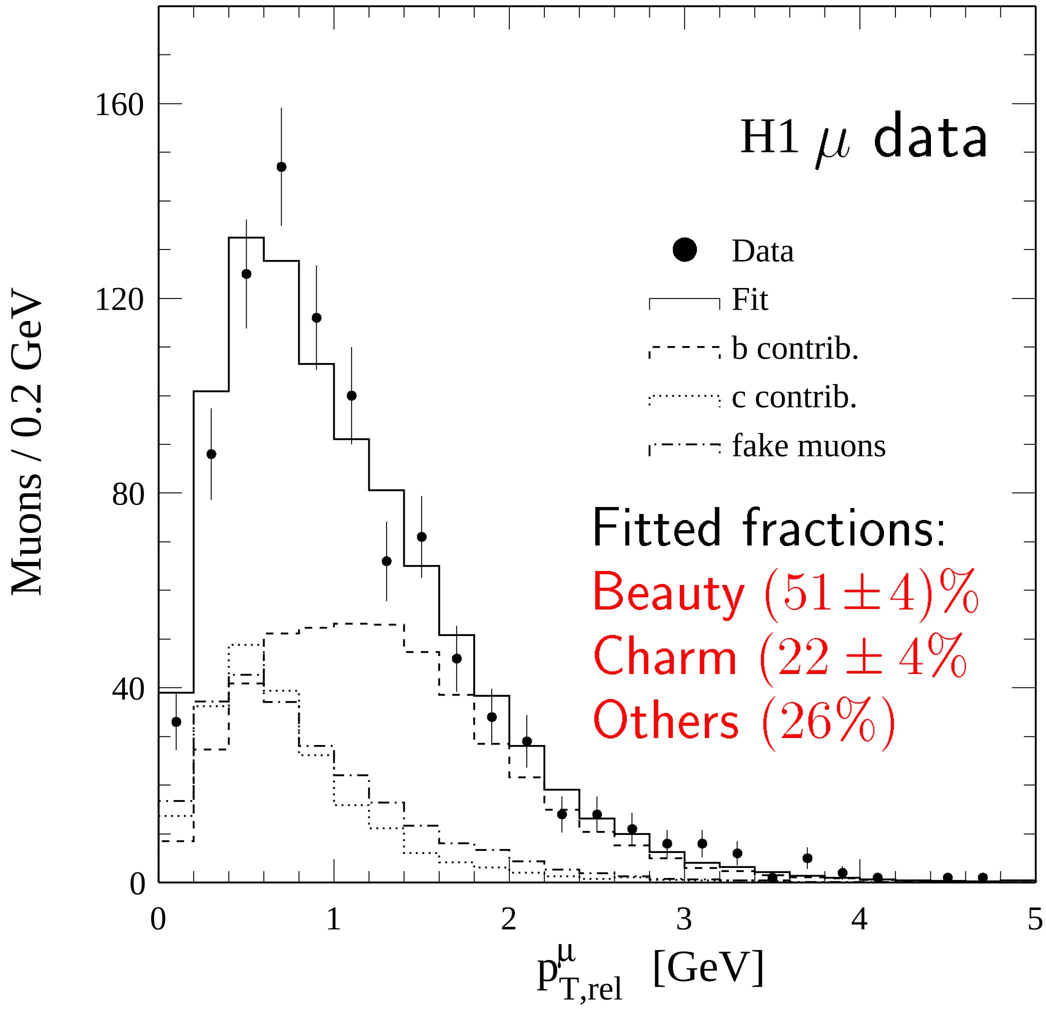
  $\sigma_{\rm uds} : \sigma_{\rm charm} : \sigma_{\rm beauty} \sim 2000 : 200 : 1$

- Measurement method:

  1.) Find leptons from b,c-decays in di-jet events

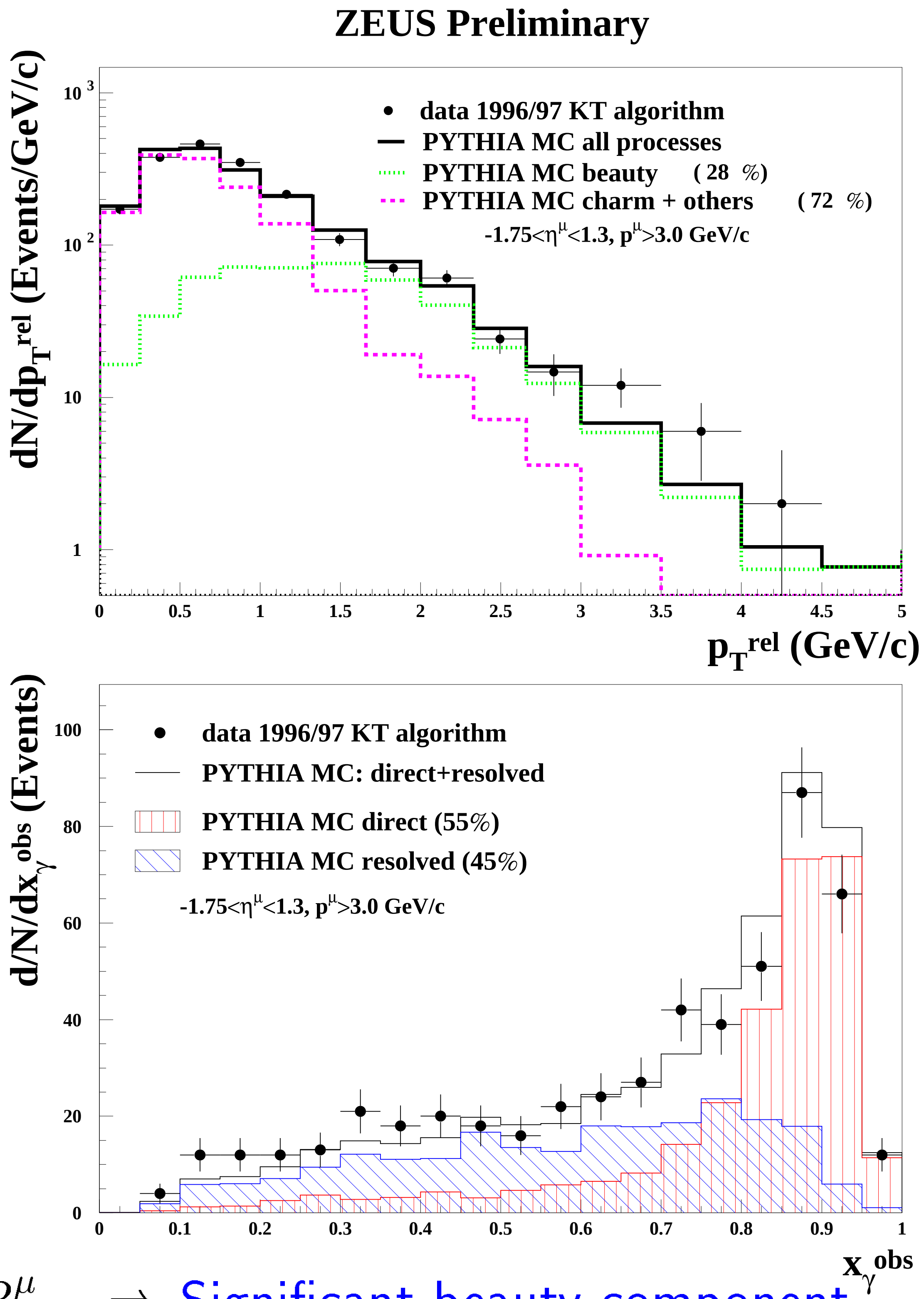
  2.) b,c separation by relative momentum of lepton to associated jet $\rightarrow P_{T,rel}$





New: Zeus μ data

- Central-backward μ data: $P_{T,rel}^{\mu}$ and x_{γ}



$P_{T,rel}^{\mu} \Rightarrow$ Significant beauty component

$x_{\gamma} \Rightarrow$ Significant resolved component in beauty enriched sample

Beauty results

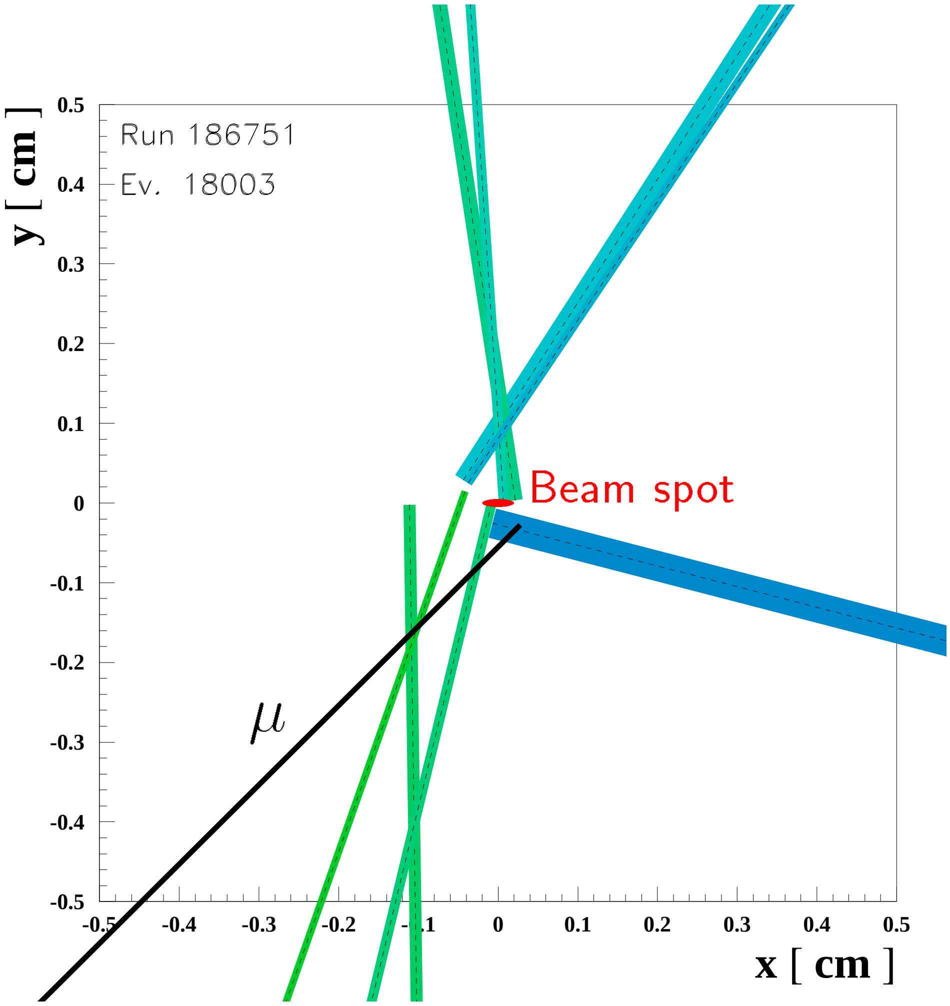
Collab.	H1	ZEUS	ZEUS	ZEUS
Channel	μ	e	μ	forw. μ
Data	1995-1996	1996-1997		
Kinematic cuts	$Q^2 < 1$ $0.1 < y < 0.8$	$Q^2 < 1$ $0.2 < y < 0.8$		
Lepton cuts P_T [GeV]	$> 2.$	> 1.6	$p > 3$	> 1.5
DiJet selection	$E_T^{1,2} > 6$ GeV	$E_T^1 > 7$ GeV $E_T^2 > 6$ GeV		
σ_{vis} [pb] Stat. err. Sys. err.	176^* ± 16 $^{+26}_{-17}$	39 ± 11 $^{+23}_{-16}$	36 ± 5 $^{+10}_{-9}$	21 ± 6 $^{+6}_{-6}$
$\frac{\text{Data}}{\text{LO-MC}}$	4.5	4-5	1.2-3	2-4
$\frac{\text{Data}}{\text{NLO}}$	1.7 $(\sim 2\,\sigma)$	3.8 $(\sim 1.4\,\sigma)$		

* H1-cross section is corrected for 2 Jet selection acceptance

$\Rightarrow$ All results above theory!

What's in the queue?

- Int. Lumi of 1998-2000 running:
  - Now: $\approx 1.2 \cdot \mathcal{L}(\leq 1997)$
  - Shutdown 9/2000: $\approx 2 \cdot \mathcal{L}(\leq 1997)$
- H1 Si-vertex detector (since 1997)
  $\Rightarrow$ Lifetime tagging of charm and beauty



$B \to \mu X$ event cand.
$PT, rel^{\mu} = 3$ GeV

Lines = tracks in the vertex region, widths $\sim$ resolution

Conclusions:

- Two scale problem:
  1. Q^2: At higher Q^2 QCD based calculations of Heavy flavor production at HERA seem reliable
  2. m_Q: Both charm and beauty photoproduction ($Q^2 \approx 0$) results overshoot NLO QCD predictions

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- Looking over the horizon ($\geq$ year 2001)
  - Hardware upgrades $\rightarrow$ improved tracking (Si-detectors, forward trackers, triggers)
  - Lumi upgrade $\rightarrow$ collecting 10 times more data $\Rightarrow$ allow deeper explorations, e.g. double tags of charm, $F_2^{b\bar{b}}$