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Charm and Beauty Photoproduction at HERA

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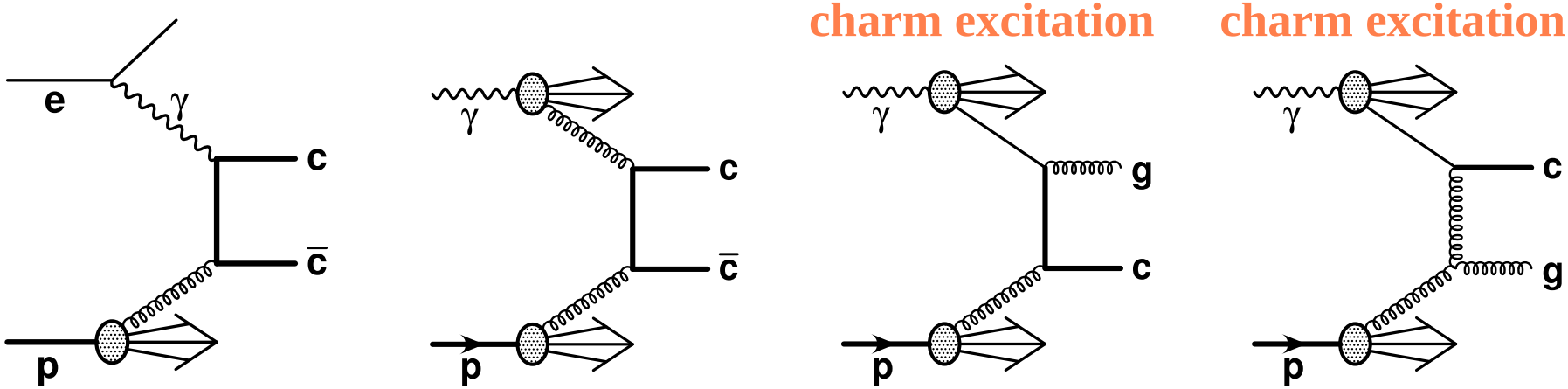
On Behalf of the ZEUS and H1 Collaborations

Introduction : charm and beauty production in ep collisions

- **dominated by Boson Gluon Fusion (BGF) at LO : $\gamma g \rightarrow c\bar{c}/b\bar{b}$ (direct/resolved)**

direct photon **resolved photon** **resolved photon charm excitation** **resolved photon charm excitation**



$\Rightarrow$ direct processes dominate, in photoproduction ($Q^2 \sim 0$) resolved play significant role

Factorisation

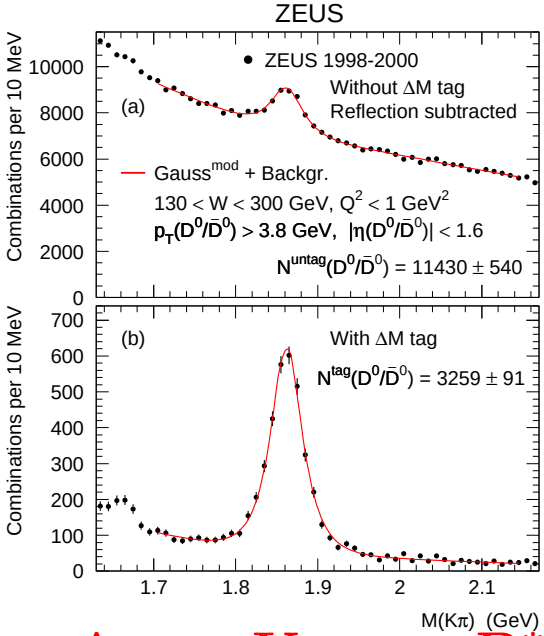
σ = proton PDF $\otimes$ $\sigma_{\gamma g \rightarrow Q\bar{Q}}$ $\otimes$ photon PDF $\otimes$ fragmentation function

$\Rightarrow$ charm/beauty production sensitive to these pieces

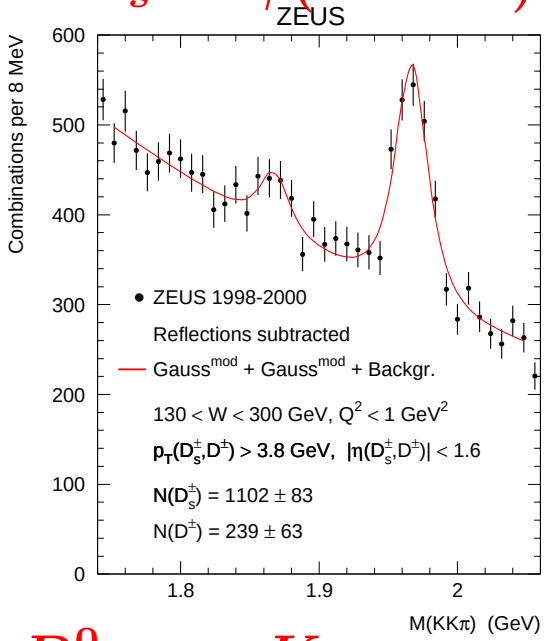
- **$m_{c/b}$ large $\Rightarrow$ useful scale pQCD : reliable predictions**
- **Cross section is directly sensitive to the gluon density in the proton**
- **Fragmentation is assumed to be universal**

Charm tagging

$D^0 \to K\pi$

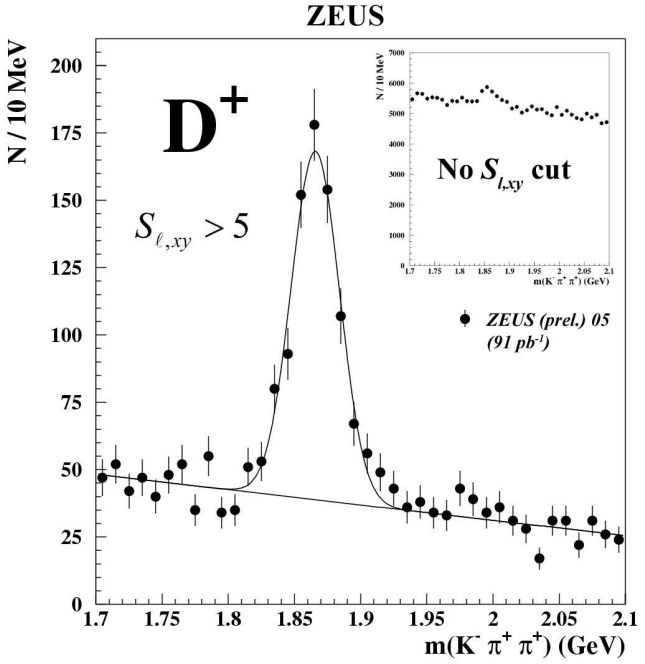


$D_s \to \phi(\to KK)\pi$

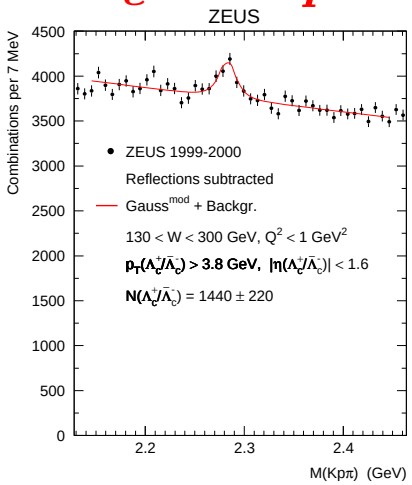


$D^{\pm} \to K\pi\pi$

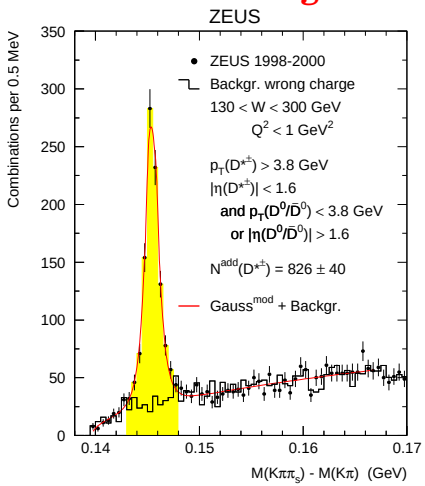
reconstruction secondary vertex

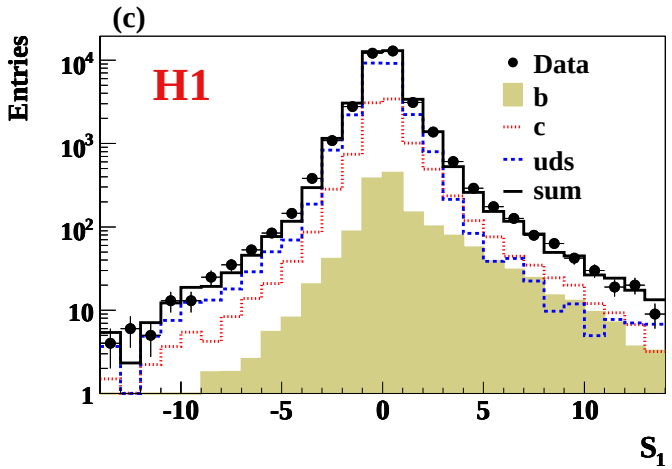


$\Lambda_c \to Kp\pi$



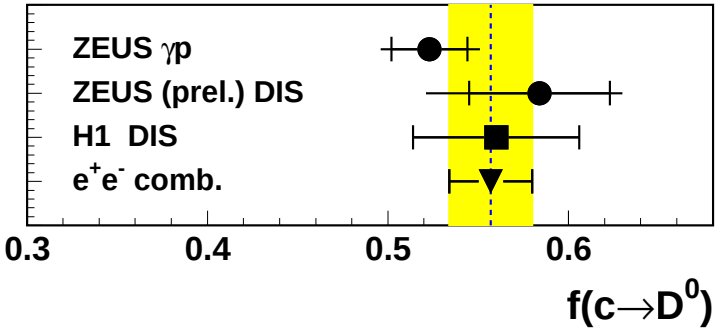
$D^* \to D^0\pi_s \to K\pi\pi$

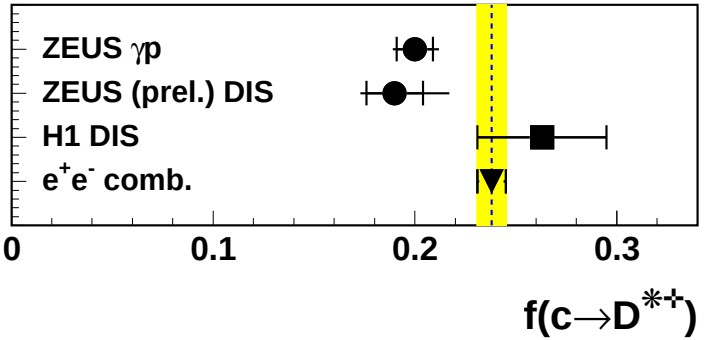


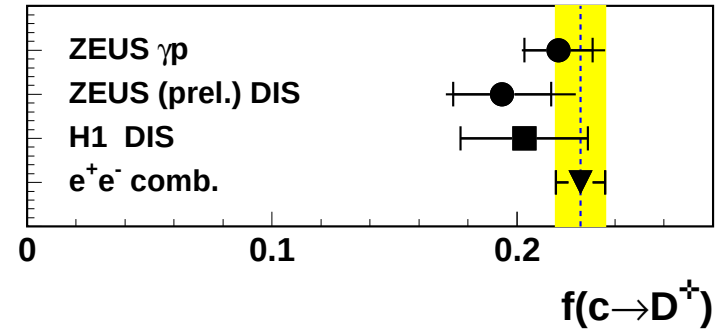


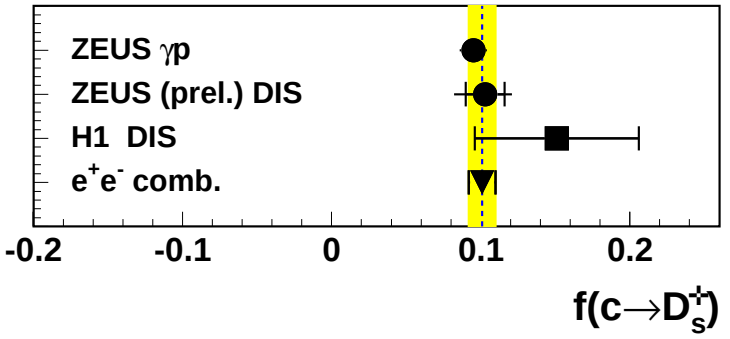
lifetime tagging

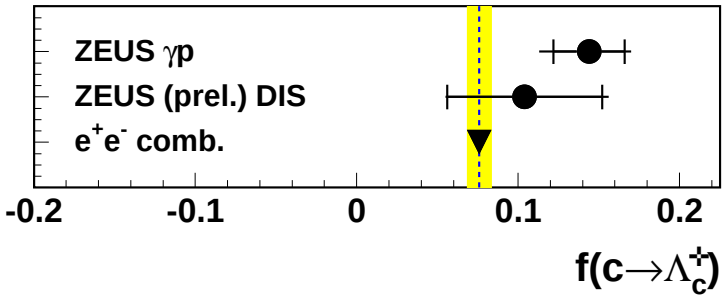
Charm fragmentation : fractions









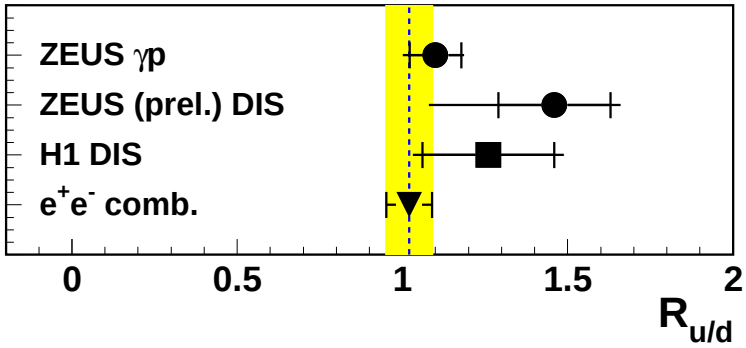


$$f(c \to D) = \frac{\sigma(D)}{\sum_i \sigma(D_i)}$$

⇒ accurate measurements at HERA : errors competitive

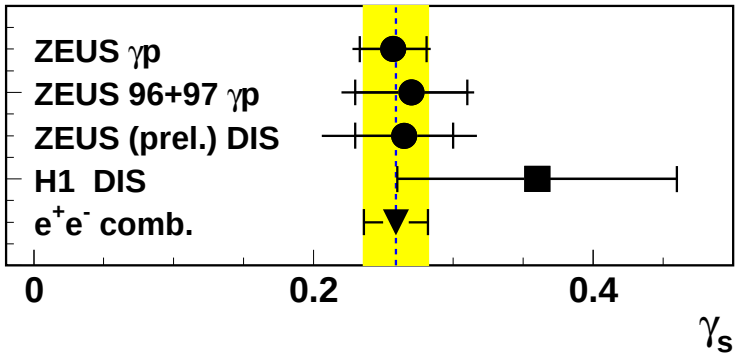
⇒ all fragmentation fractions in agreement with world average : universality

Charm fragmentation : ratios



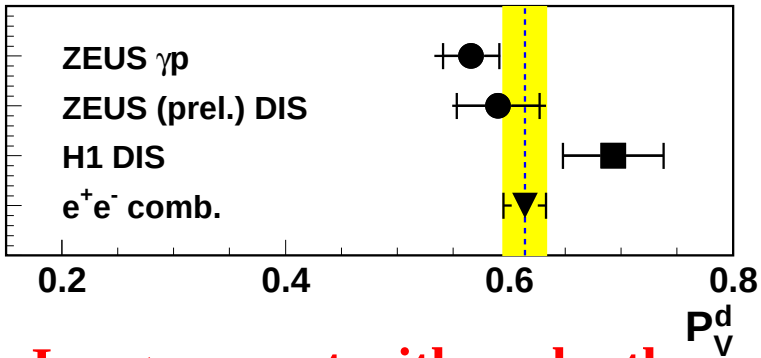
ratio neutral to charged D meson production

$\Rightarrow$ consistent with 1



s quark suppression factor

$\Rightarrow$ D_s less frequently produced than D^0 and $D^{\pm}$

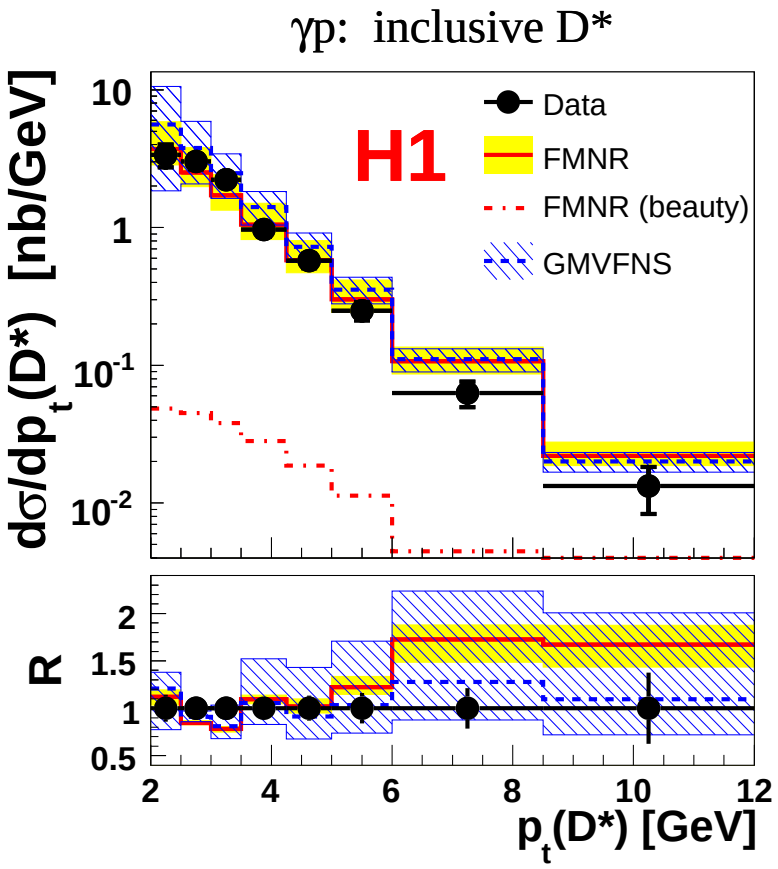


fraction of D mesons produced in a vector state

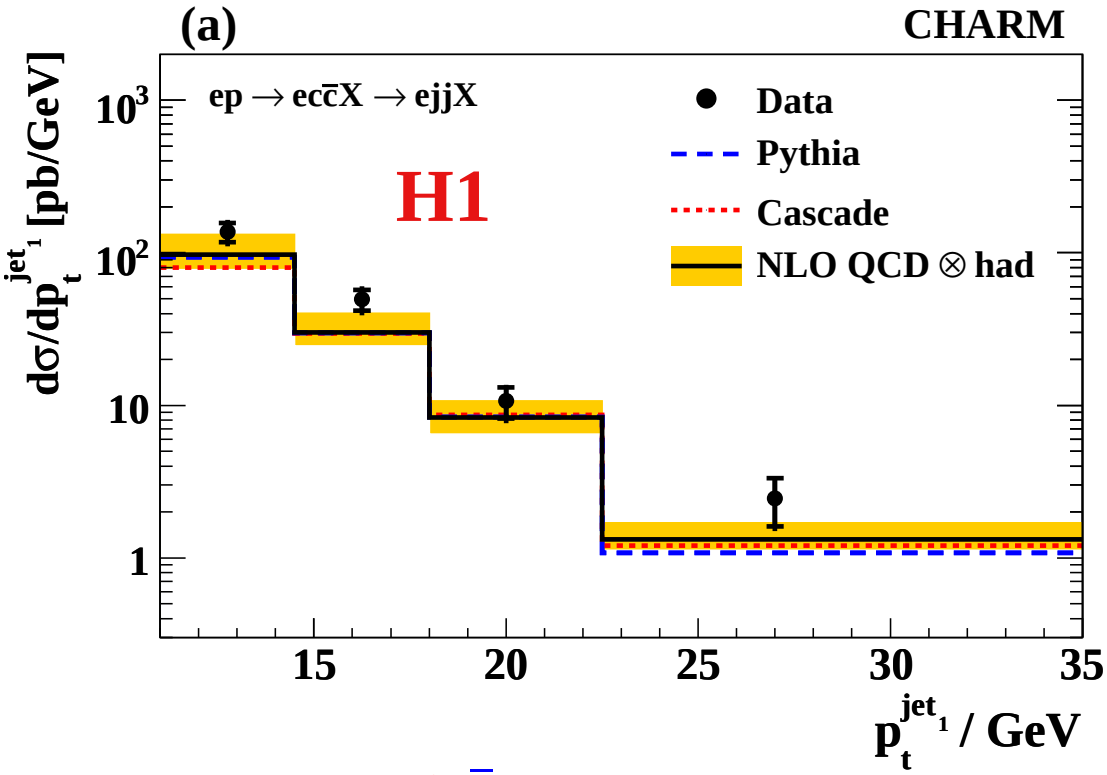
$\Rightarrow$ lower than $3/4$, from naive spin counting

$\Rightarrow$ **In agreement with each other, expectation and world average, but naive spin counting does not work** $(P_V \neq 3/4)$

D^* and dijet photoproduction

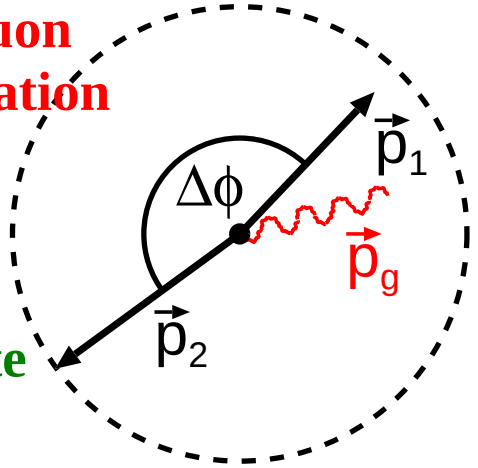


- D^* selection in photoproduction
- **precision measurement :**
  theo. uncertainties larger than exp.
- **data well described by NLO**



- $ep \rightarrow e\, c\bar{c}/b\bar{b}\, X \rightarrow e\, jj\, X$
  extended p_T range
- **jet ≈ parton, had. uncertainties suppressed**
- c/b **events selected using vertex detector**
- **data reasonably well described by NLO**

D^* photoproduction : D^* jet correlations

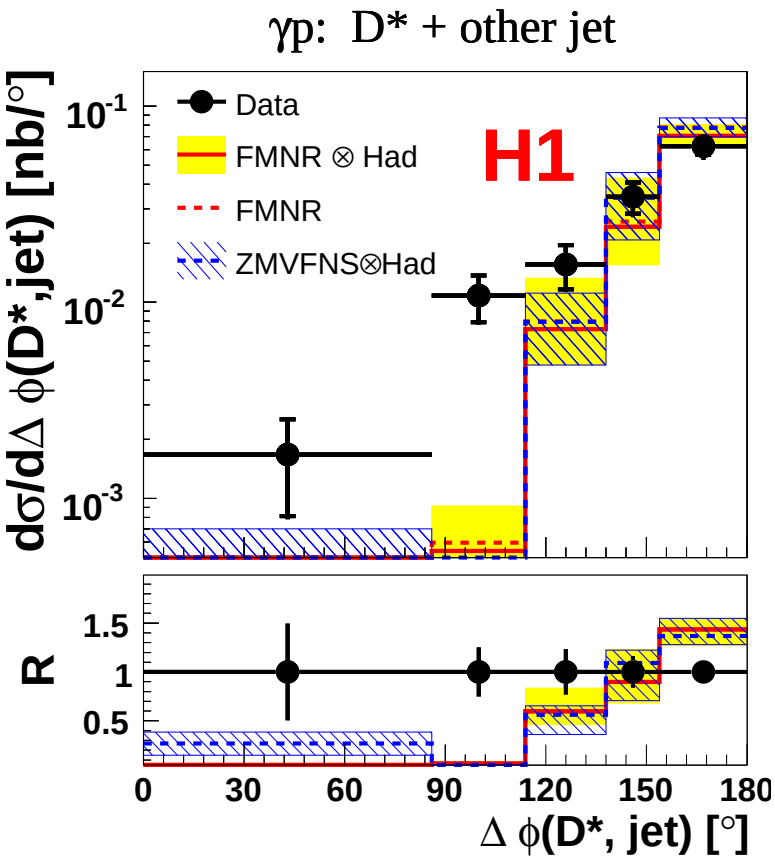


D^*+(untagged)jet $\Rightarrow$ test higher order QCD contributions

php : γ and parton collide head-on
$\Rightarrow$ if no gluon emission, $2 \rightarrow 2$ process, "back to back" final state

are we sensitive to gluon radiation?

- measure cross section in $\Delta\phi(D^*, jet)$
- only 25% from back to back configurations (i.e. $\Delta\phi \sim 180°$)
  $\Rightarrow$ significant contribution from higher order QCD radiation
- NLO calculation does not describe region $\Delta\phi \sim 100°$
  $\Rightarrow$ sensitivity to higher order contributions

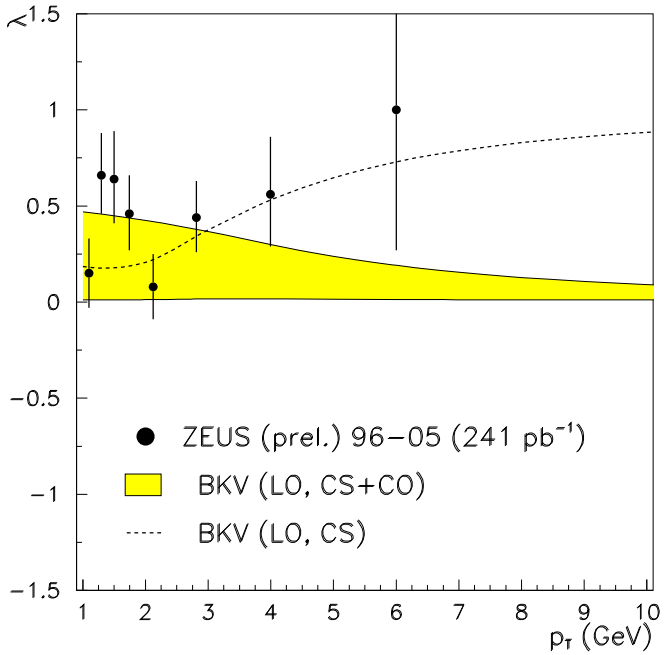


J/ψ inelastic photoproduction

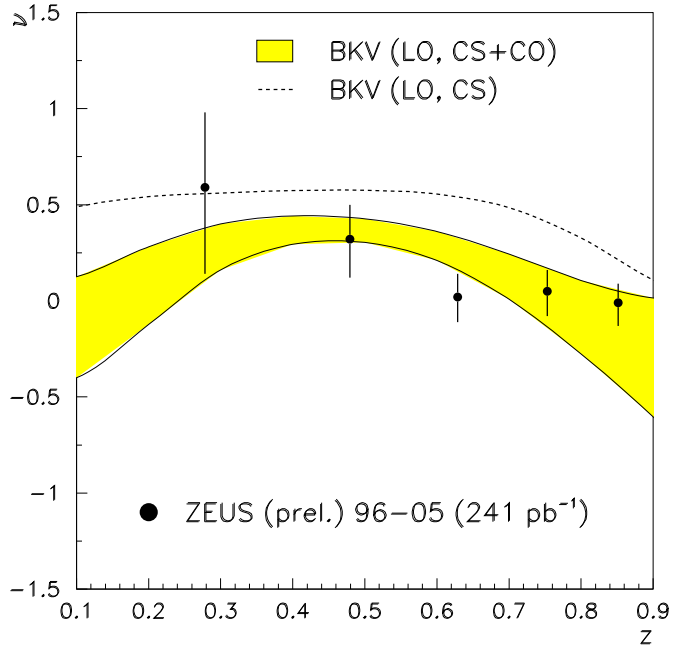
- $ep \to e\, J/\psi\, X$, $J/\psi \to \mu^+\mu^-$
- decay angular distributions ("helicity") λ, ν measured using HERA I+II data

$$\frac{d^2\sigma}{d\Omega dy} \sim \lambda(y)\cos^2\theta + 1/2\nu(y)\sin^2\theta\cos^2 2\varphi + \dots$$

y : z or $p_T(J/\psi)$, $z = E(J/\psi)/E(\gamma)$



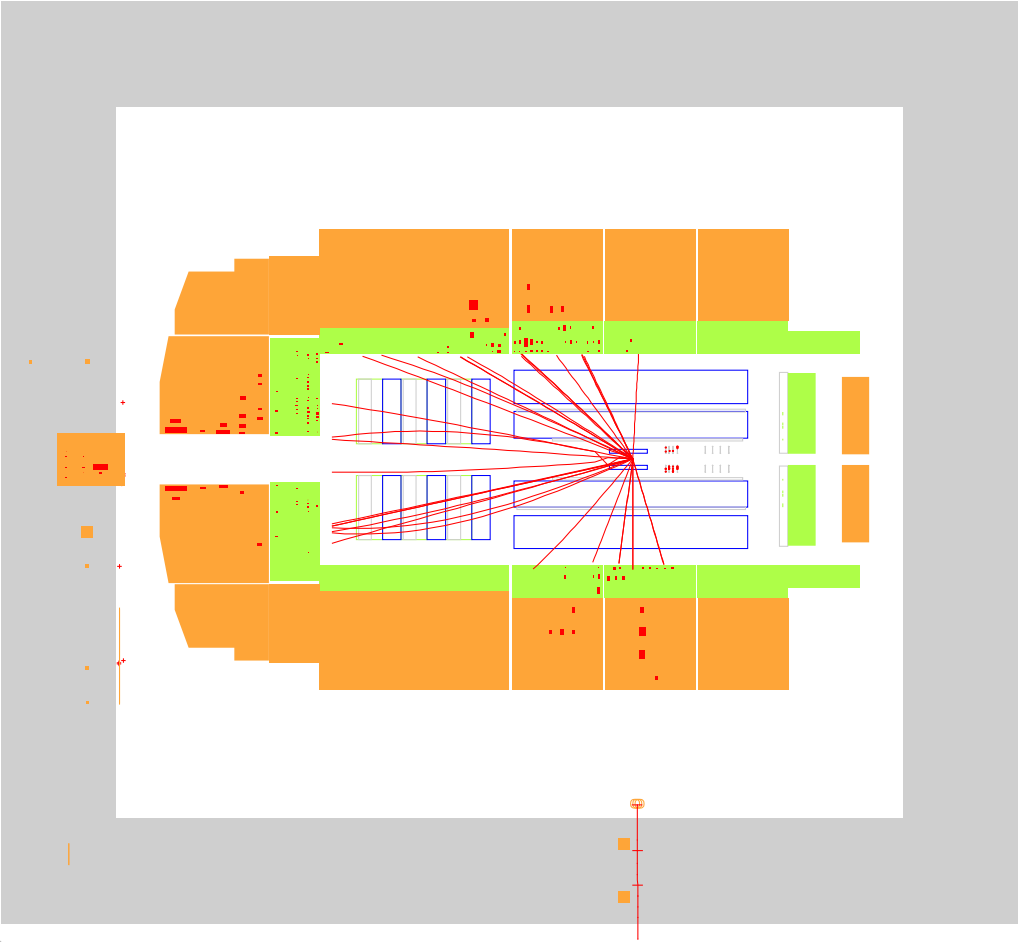
⇒ distributions not dependent on parameters affecting the absolute normalisations of cross section ($m_c, \alpha_s, \dots$) : main source of theo. uncertainties gone

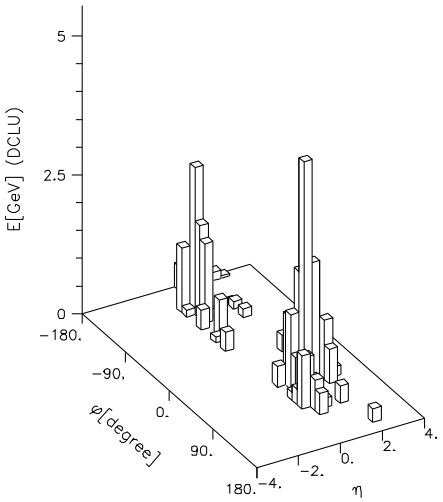


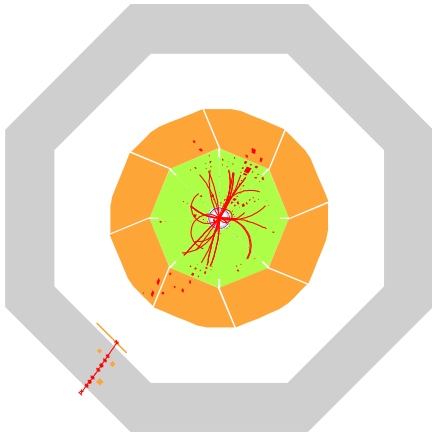
- comparison to LO CS and $CS + CO$ models
  - ⇒ the two models differ at high $p_T(J/\psi)$, where statistics is poor
  - ⇒ deviations from CS model only for $z > 0.6$

Beauty tagging

Candidate to $b\bar{b}$ event







- Reconstruction of B in particular decay channels does not work : $B.R \sim 10^{-4}$
- Use semileptonic decays : μ in final state

$b\bar{b}$ production : $D^*\mu$ tag

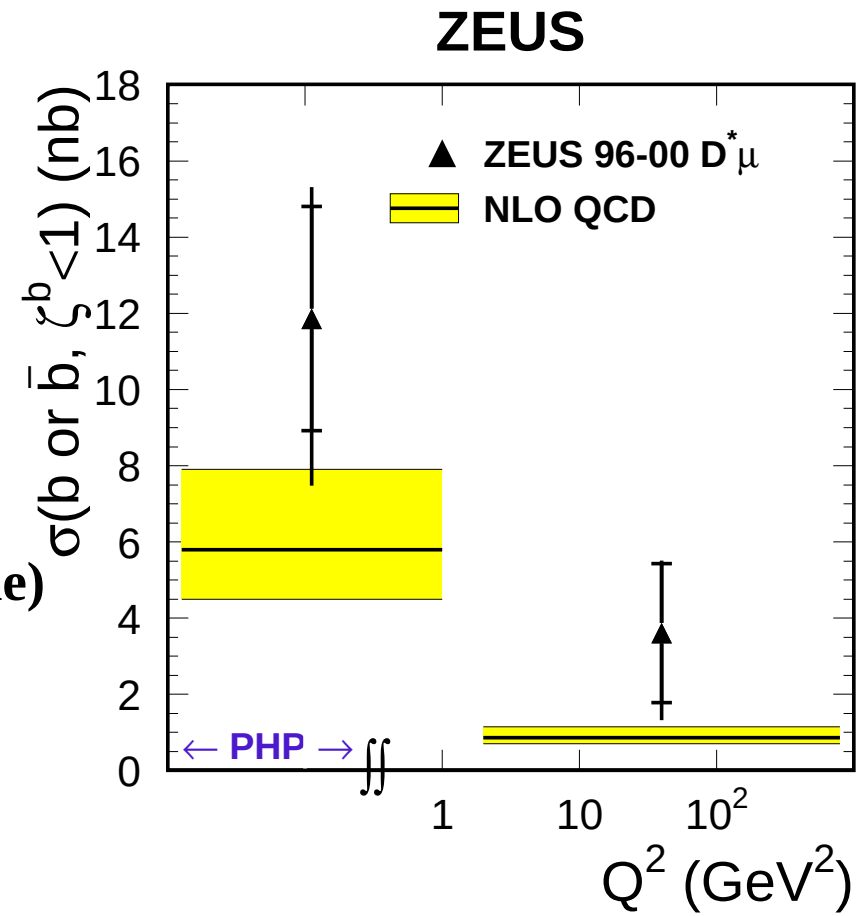
$ep \to e\, b\bar{b}\, X \to e\, D^*\mu\, X' \Rightarrow$ **enriched b sample, backgrounds strongly suppressed**

$\Rightarrow$ can measure up to very low p_T

$p_T(\mu) > 1.4$ GeV, $p_T(D^*) > 1.9$ GeV

(close to b production threshold)

- **$\Delta R(D^*, \mu) = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$ distribution used to extract b-signal (MC)**
- **visible and extrapolated b quark cross section measured in both photoproduction and DIS, compared to NLO (fixed order, massive scheme) theoretical predictions**



$\Rightarrow$ measurements exceed the NLO predictions, but compatible within the errors

$b\bar{b}$ production : $\mu\mu$ tag

$ep \rightarrow e\, b\bar{b}\, X \rightarrow e\, \mu\mu\, X'$

$\Rightarrow$ $b\bar{b}$ enriched sample, backgrounds suppressed

- larger statistics, lower p_T threshold than $D^*\mu$
  $\Rightarrow$ nearly full $b\bar{b}$ phase space available
  (i.e, very small extrapolation in cross sections)

- measure total $b\bar{b}$ cross section

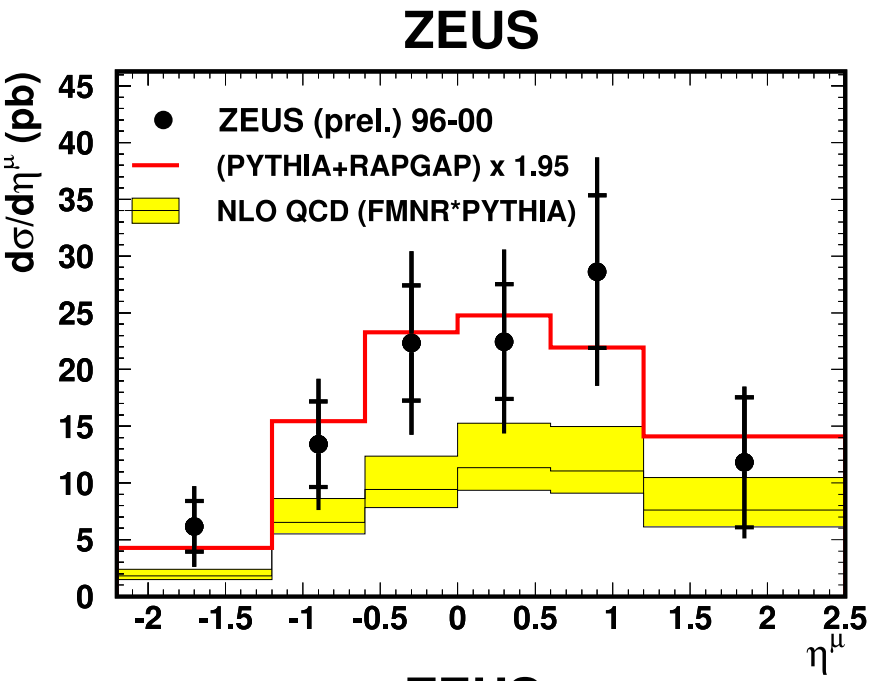
$\sigma_{TOT}(b\bar{b}) = 16.1 \pm 1.8(stat)^{+5.3}_{-4.8}$ nb

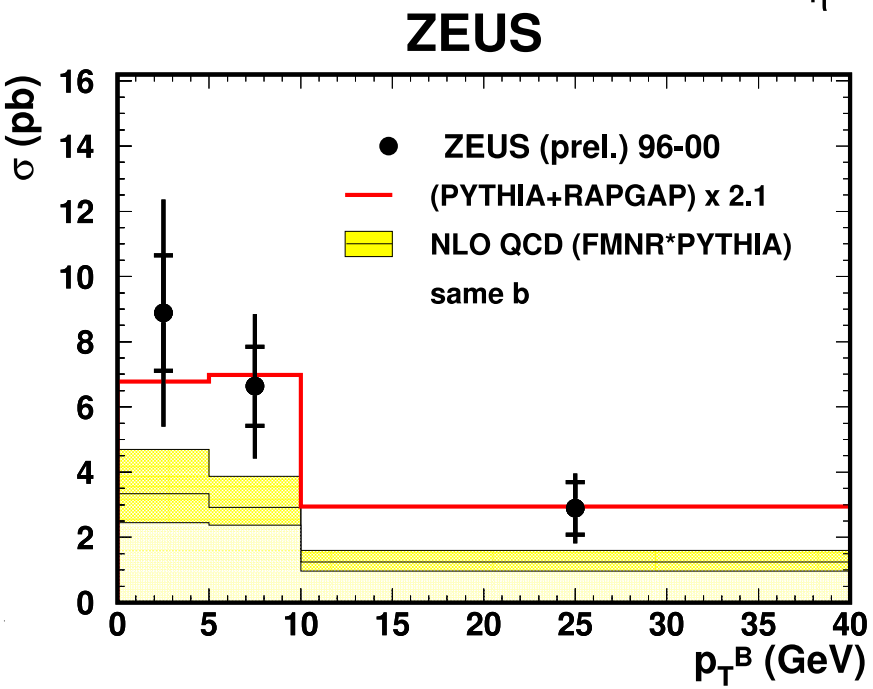
NLO : $6.8^{+3.0}_{-1.7}$ nb

theo. prediction $2.3^{+1.0}_{-1.2}$ lower than measurement

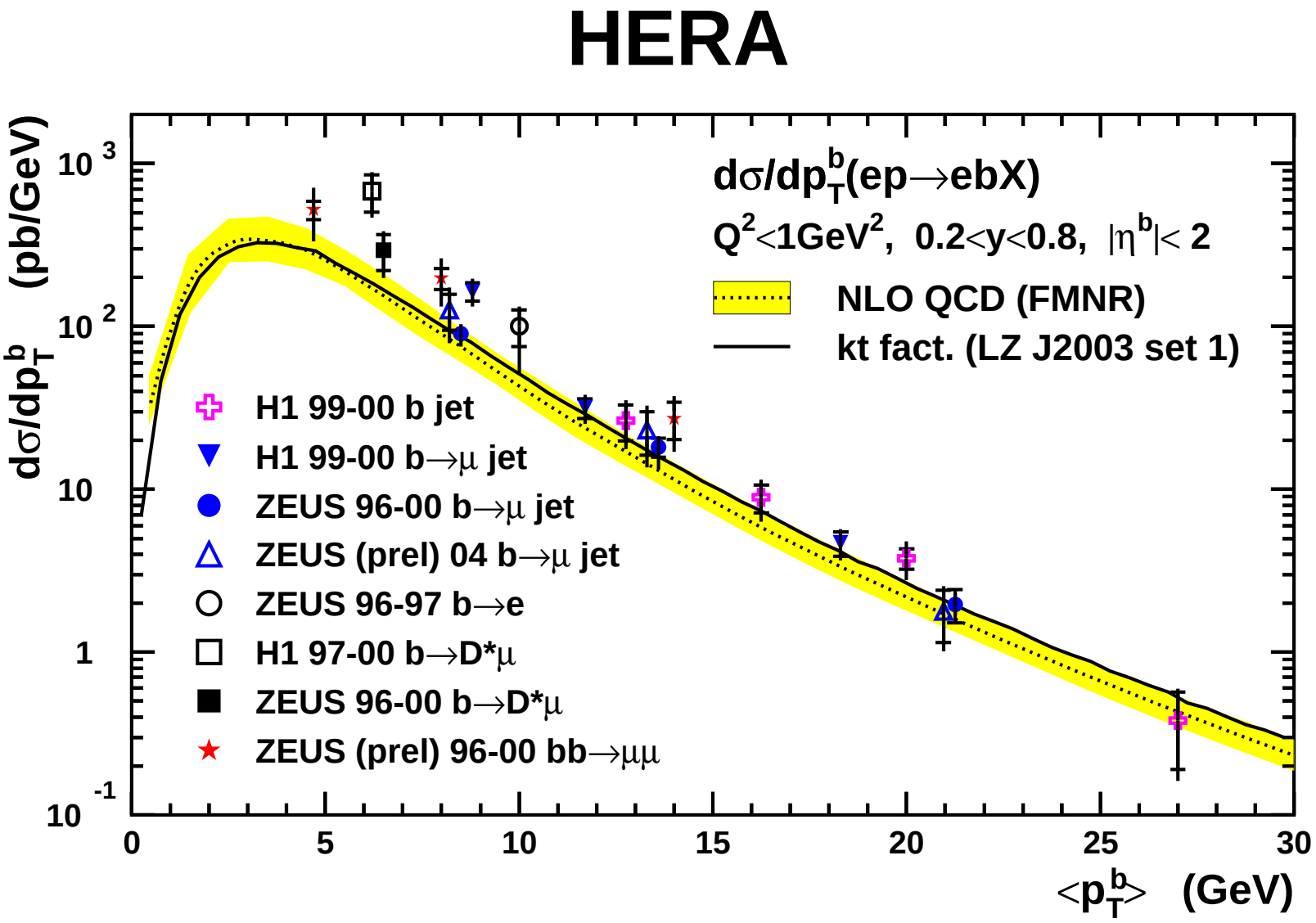
- measure differential cross sections
  μ, B hadron, and b quark level

$\Rightarrow$ NLO prediction agree in shape,
but underestimate the data





$b\bar{b}$ production : combined measurements



Summary

- **Charm fragmentation fractions/ratios and fragmentation function measured**
  → accurate measurements : HERA errors competitive
  → Evidence that charm fragmentation is universal in e^+e^- and ep

- **Description of charm cross sections by QCD good in general,**
  but fails in the details

- **New measurements : jets . . . give more details of final state/event kinematics**
  → Charm γp and jets showing the need for higher order calculations
  theoretical developments needed (MC@NLO. . .)

- **In beauty production the tendency of the data is to be higher than the NLO,**
  but consistent within the uncertainties
  → more precise data needed to constrain the theories