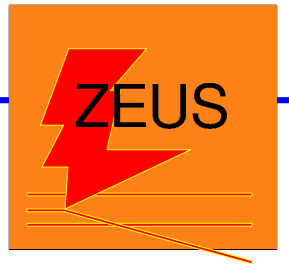
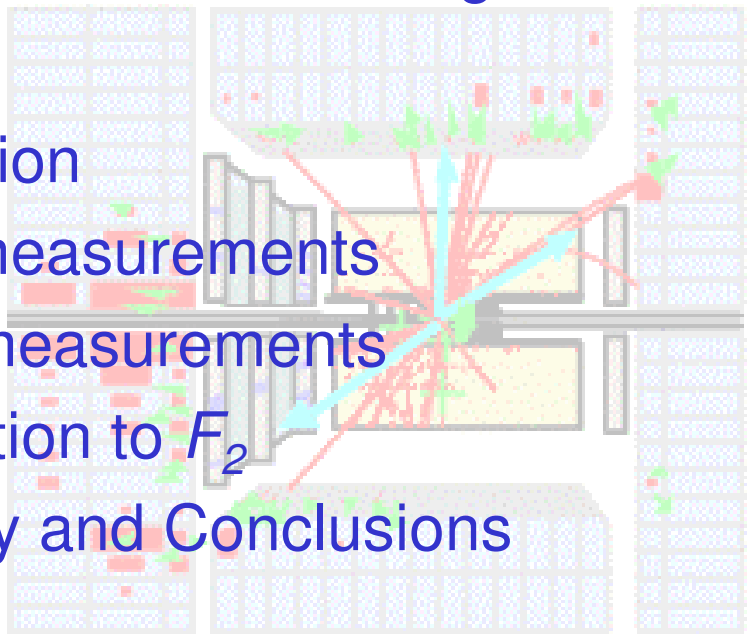


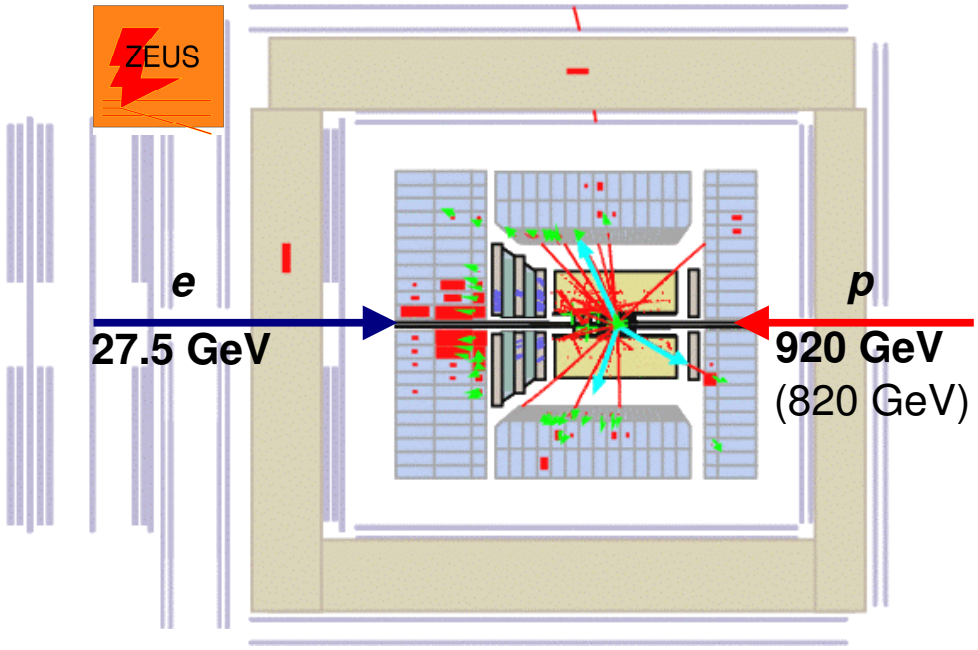
Heavy quark measurements at HERA

B. Kahle, DESY Hamburg

- Introduction
- Charm measurements
- Beauty measurements
- Contribution to F_2
- Summary and Conclusions



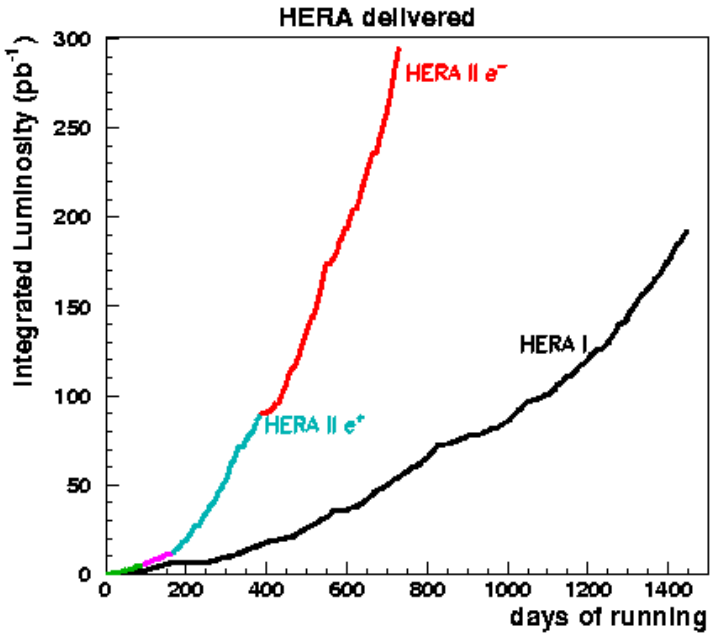
HERA: *ep*-collisions at H1 and ZEUS



ep center of mass energy:	
1992 - 97:	300 GeV
98 - 2005:	318 GeV

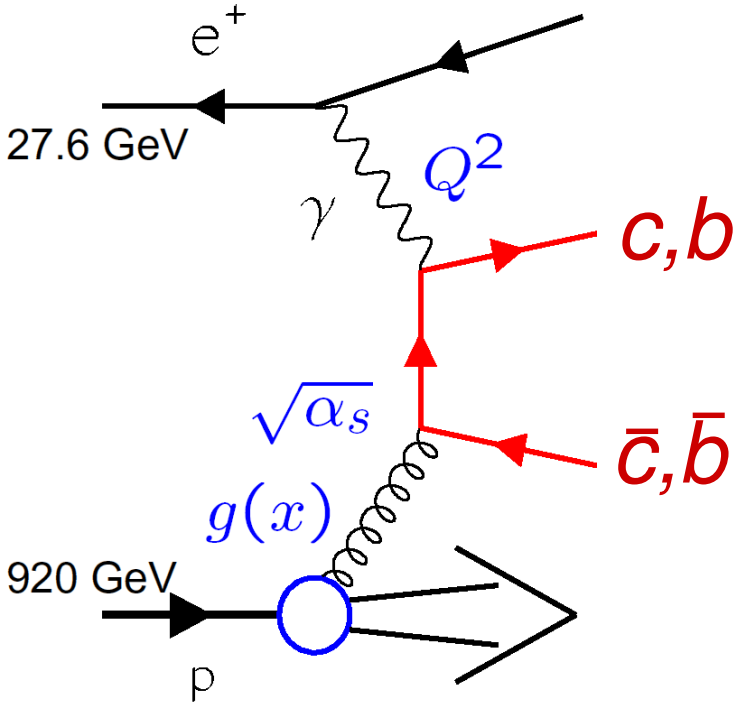
Integrated Luminosity (e.g. ZEUS physics):

Year	e^+p	e^-p
96-00 (HERA I)	105 pb^{-1}	17 pb^{-1}
03-05 (HERA II)	41 pb^{-1}	152 pb^{-1}
06-07 (expected)	about factor 2 more	



Heavy Flavour production mechanism

Dominant process in *ep*-collisions: **Boson-Gluon-Fusion**



Kinematic variables:

$Q^2 = -q^2$ photon virtuality, squared momentum transfer

$x = \frac{Q^2}{2Pq}$ Bjorken scaling variable, for $Q^2 >> (2m_Q)^2$: momentum fraction of p constituent

Two kinematic regimes:

- Photoproduction (γp): γ quasi-real $Q^2 < 1$ GeV^2
- Deep inelastic scattering (DIS): $Q^2 > 1$GeV^2

Multiple scales:

$m_{c,b}$ ~ 1.3 (5) GeV
$p_t^{c,b}$ ~ typically few GeV
Q^2 $\gtrsim$ 1 GeV^2 in DIS

→ different pQCD approaches

Charm tags

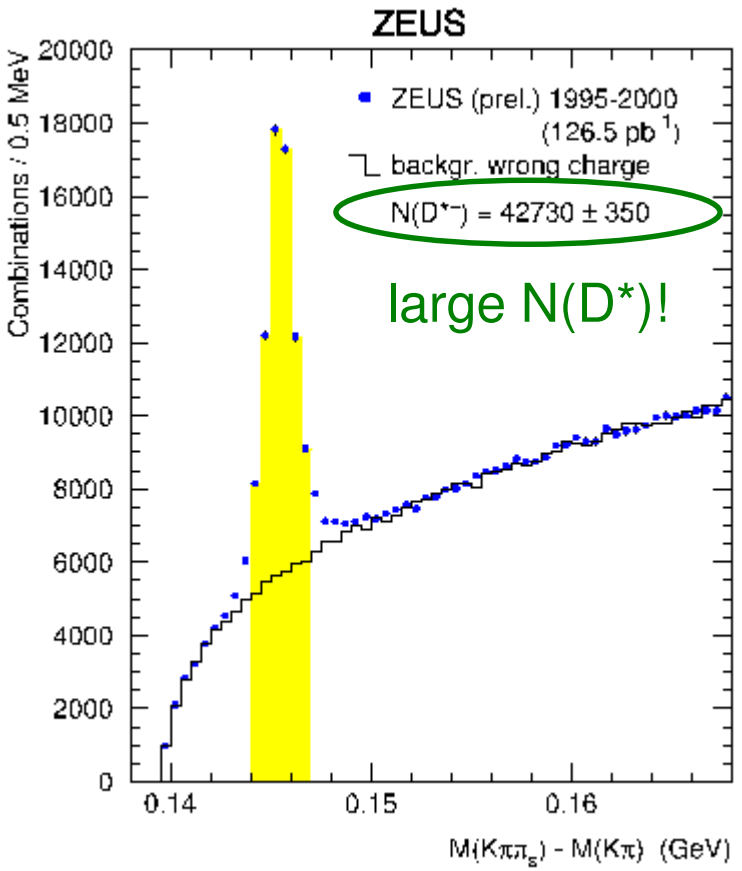
$\sigma_{uds} : \sigma_{charm} : \sigma_{beauty}$

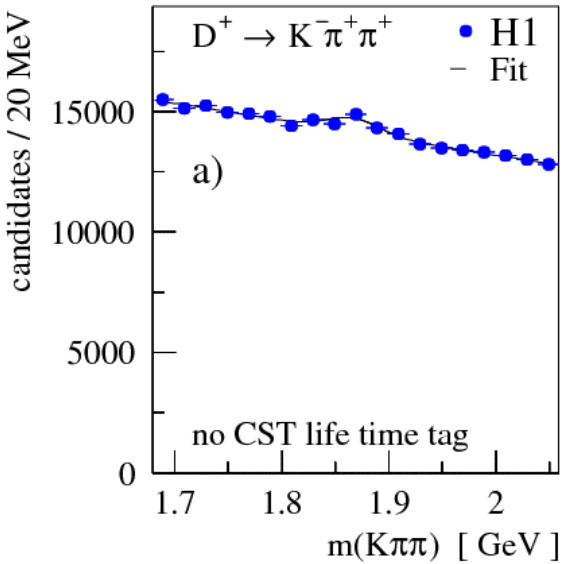
~2000 : 200 : 1

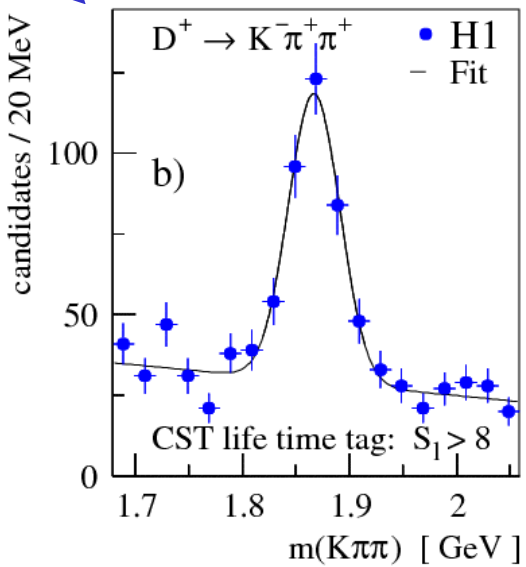
↳ HERA is a charm factory

Measurements using:

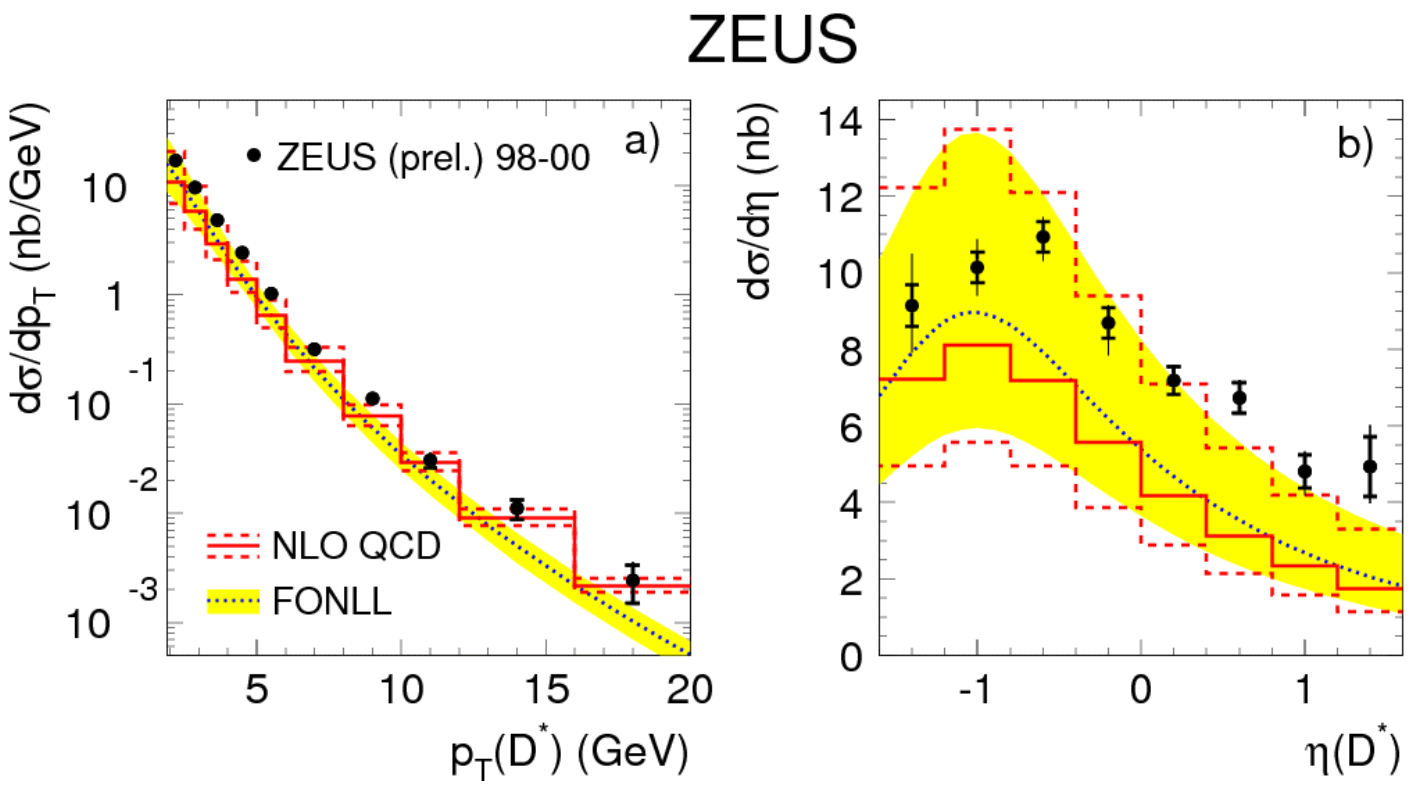
- meson tag, e.g. D*-> K π π →
- lifetime tag, e.g. D^+ (or inclusive)







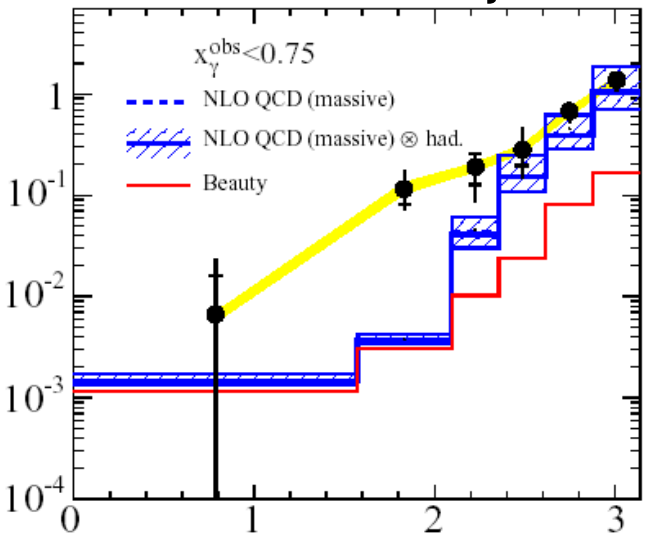
Charm in photoproduction



Data described by NLO QCD, data tend to be higher.
Measurements much more precise than calculations

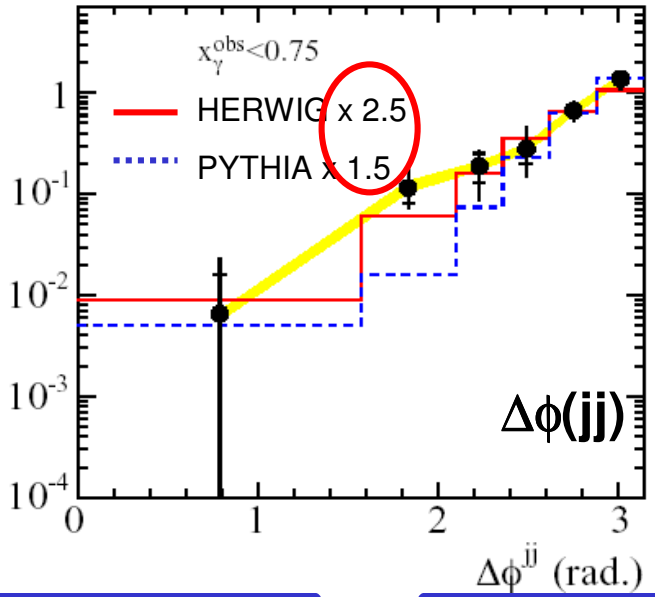
NLO vs. LO + parton shower

ZEUS charm + dijet



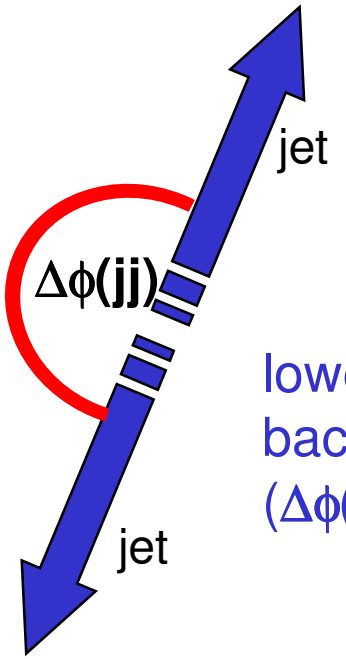
NLO

norm. OK
shape NOT



LO+PS

shape OK
norm. NOT



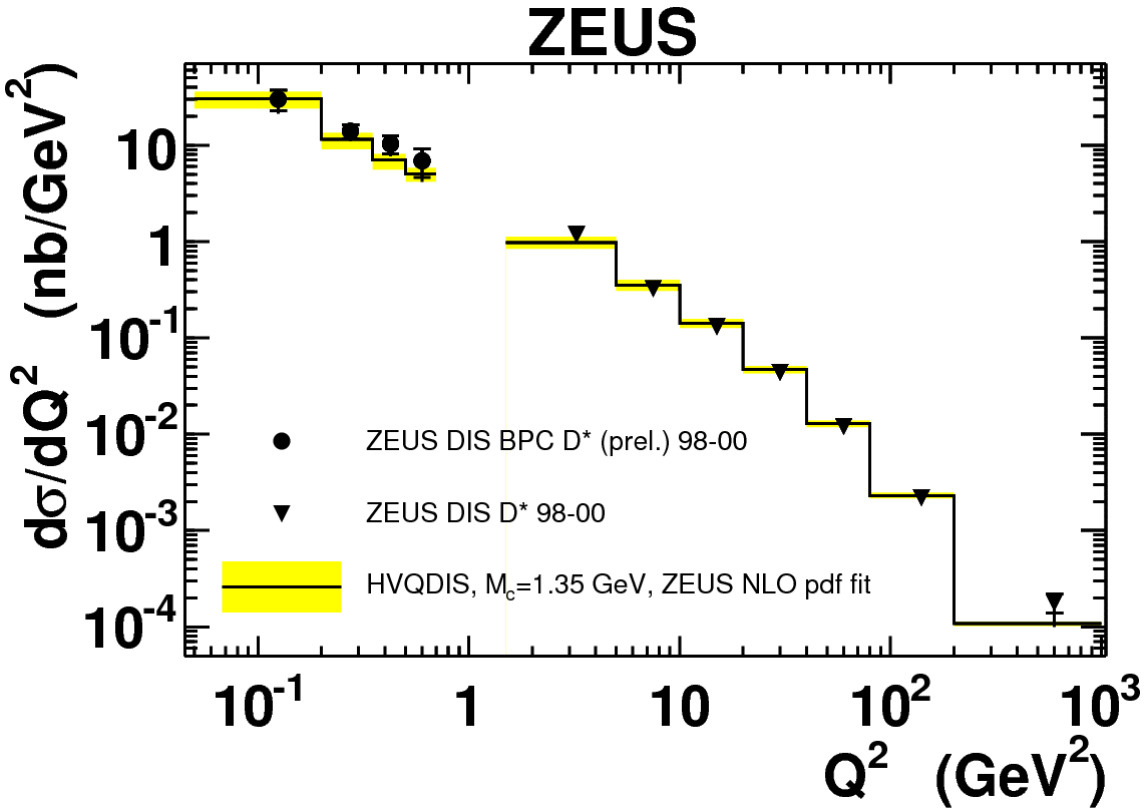
lowest order:
back-to-back
($\Delta\phi(jj) \sim \pi$)

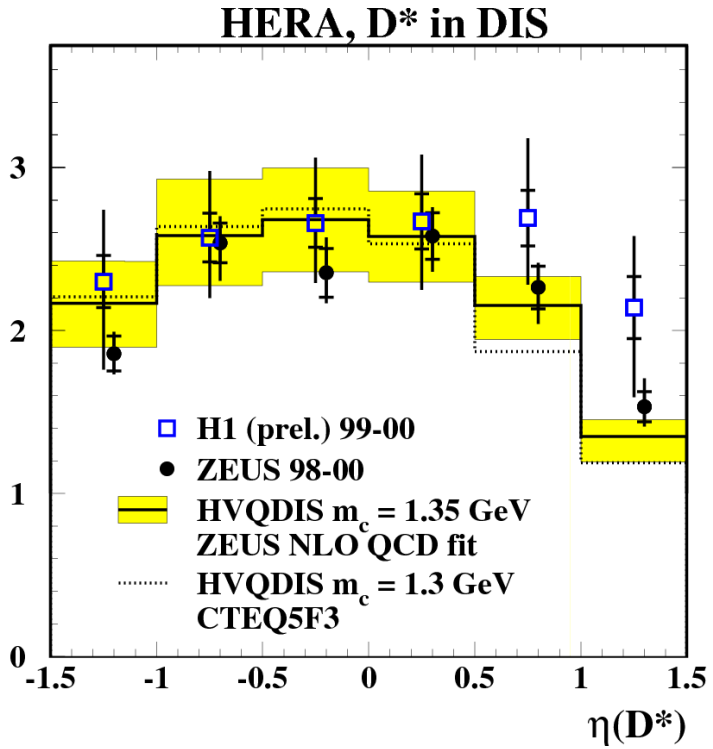
we need
NNLO

or

NLO+PS
(MC@NLO)

Charm in DIS



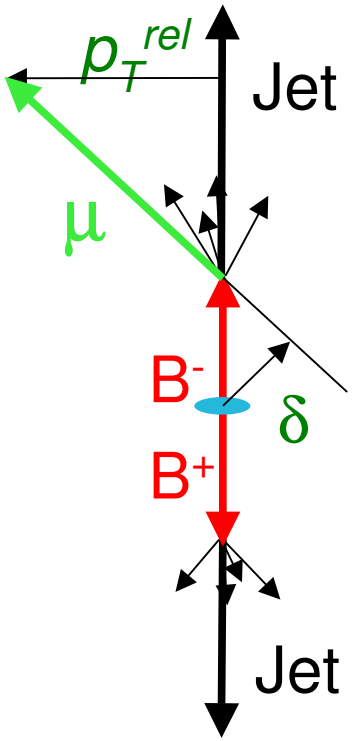


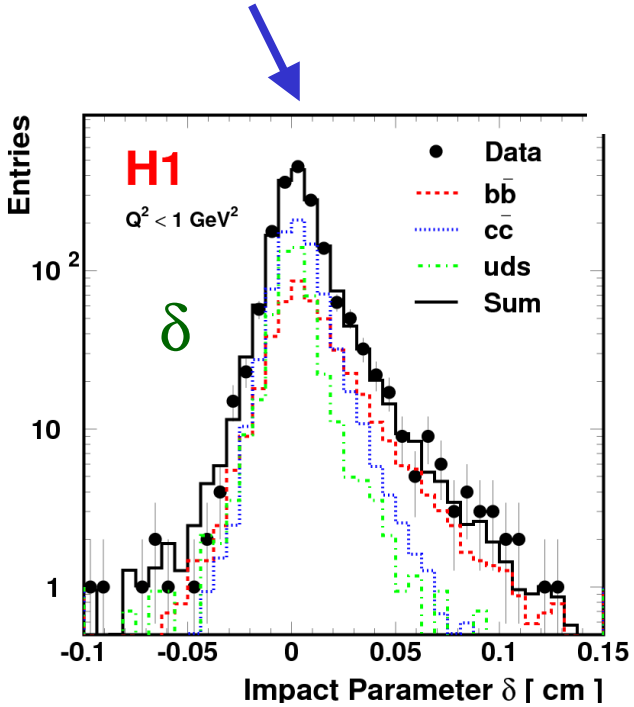
Data described by NLO QCD over 5 orders of magnitude

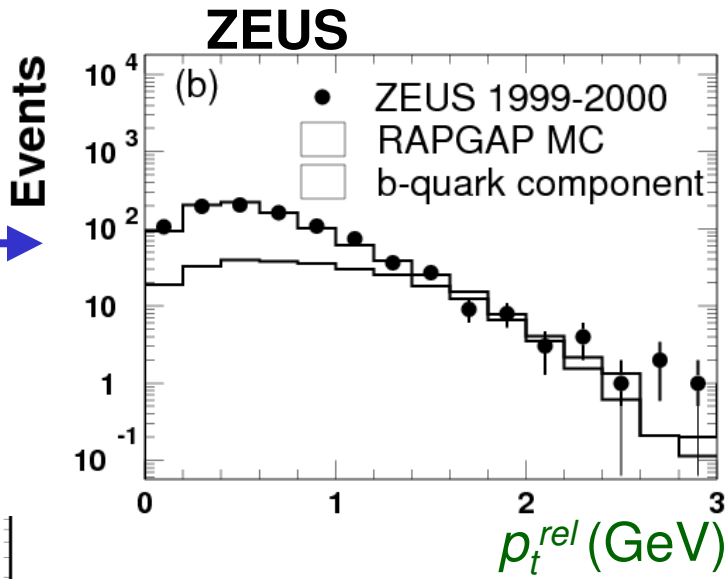
Beauty tag with μ+jets

Use μ from semileptonic decay and separate *b* and *c* by:

- Large B mass: p_t^{rel} (p_t of μ relative to jet axis)
- Large B-Lifetime: μ Impact-Parameter δ



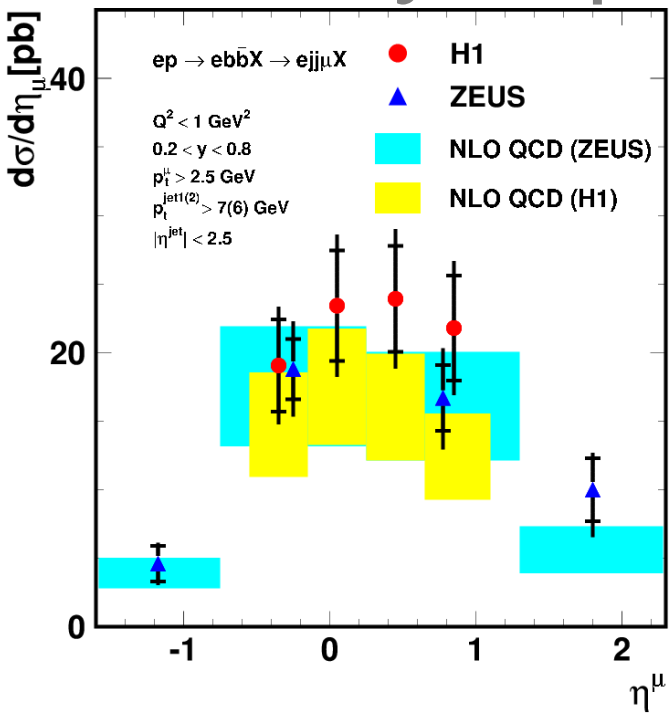


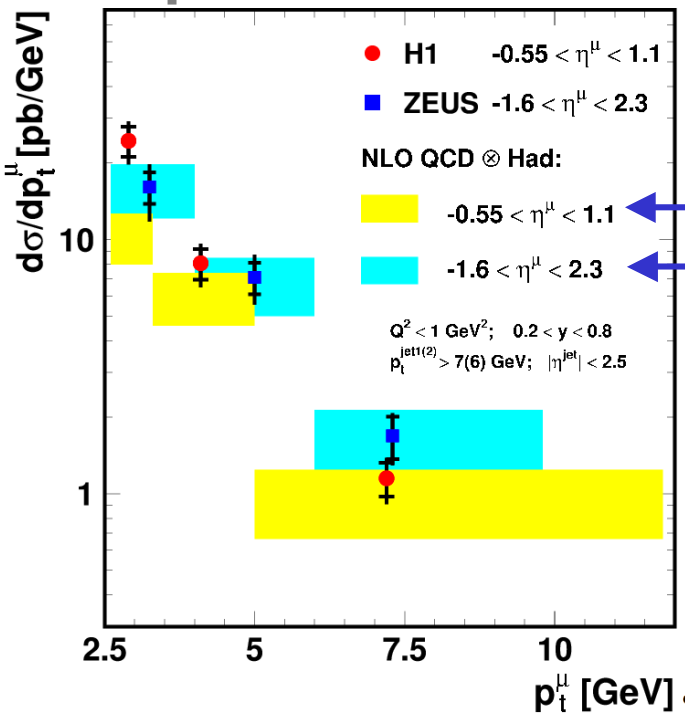


shapes in p_t^{rel} and δ from MC (δ for HERA I only H1)

↳ *b*-fraction ~ 30 %

Beauty in photoproduction and DIS



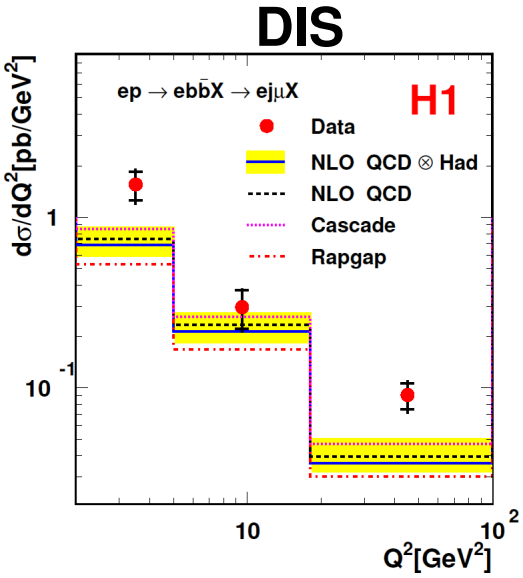


diff. kin. regions!

Reasonable description of H1 and ZEUS data by NLO

H1 data above prediction at low p_t^μ

Q^2 shape is described, data slightly above the NLO prediction

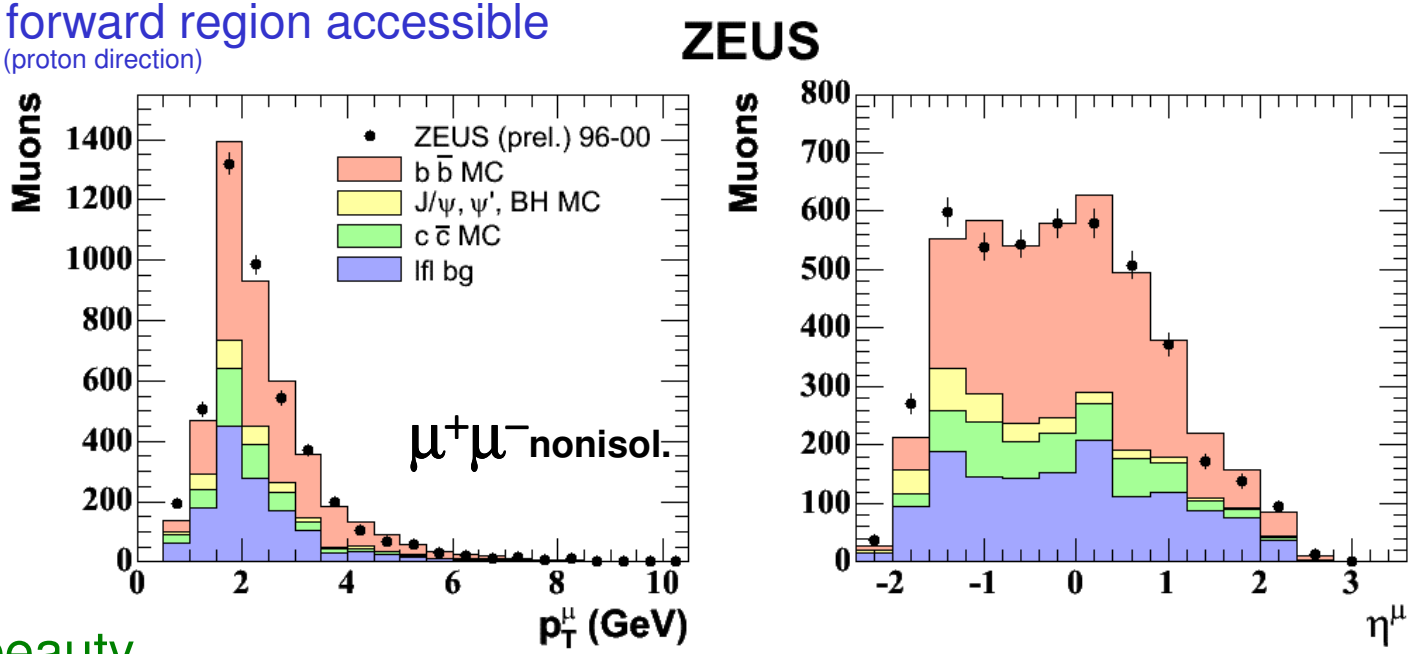


Double tagging of $b\bar{b}$ pair

- two direct flavour tags, e.g. D*+μ or μ+μ
  - large bg. reduction, no jets needed
  - low p_t and forward region accessible

(proton direction)

uds bg. indirectly from like sign μμ



b-fraction ~ 50% beauty

↳ measure **total beauty production cross section** at HERA:

$$\sigma(ep \to b\bar{b} + \text{anything}) = 16.1 \pm 1.8(\text{stat.})\ ^{+5.3}_{-4.8}(\text{sys})\ \text{nb}$$

$$\sigma_{NLO} = 6.8\ ^{+3.0}_{-1.7}\ \text{nb} \quad \text{(FMNR+HVQDIS)}$$

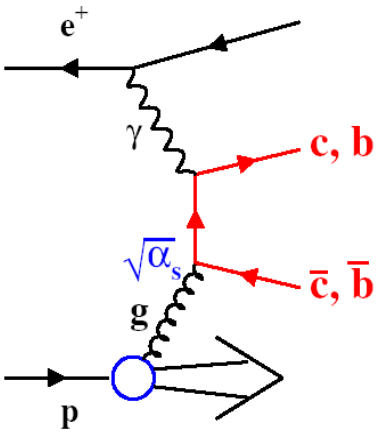
Charm contribution to F_2

$$\frac{d^2\sigma^{ep\to c\bar{c}X}}{dxdQ^2} = \frac{2\pi\alpha^2}{Q^4 x}\left\{\left[1+(1-y)^2\right]F_2^{c\bar{c}}(x,Q^2)+\ldots\right\}$$

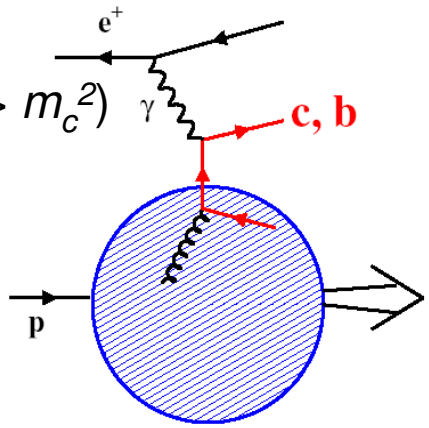
(see talk of Kunihiro Nagano)

test/constrain gluon density

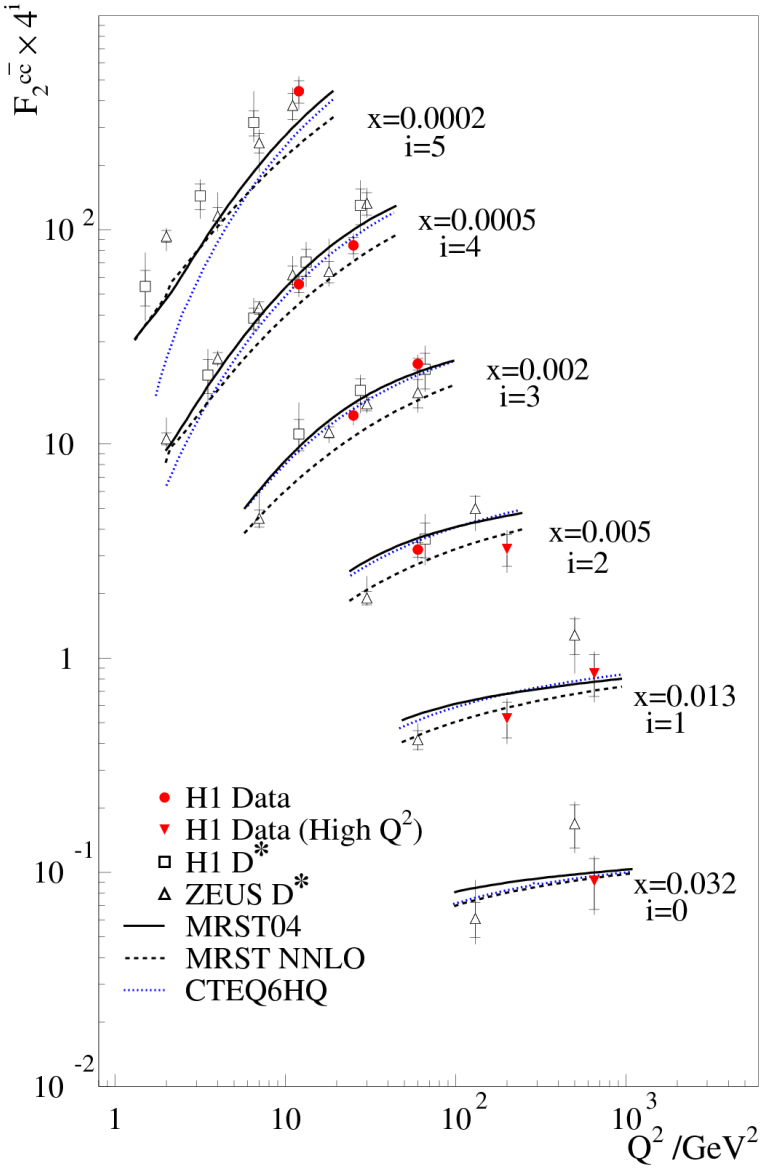
or



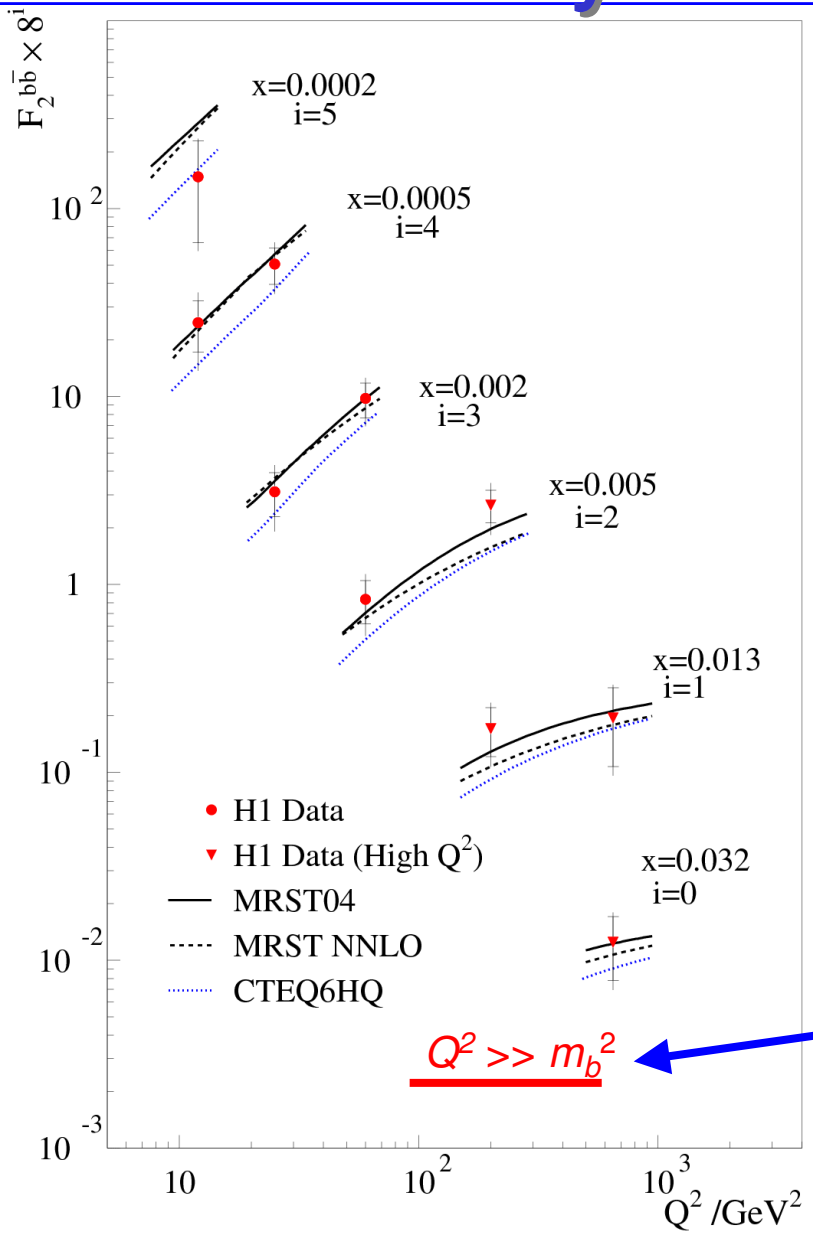
($Q^2 >> m_c^2$)



obtain virtual charm content (PDF) of proton

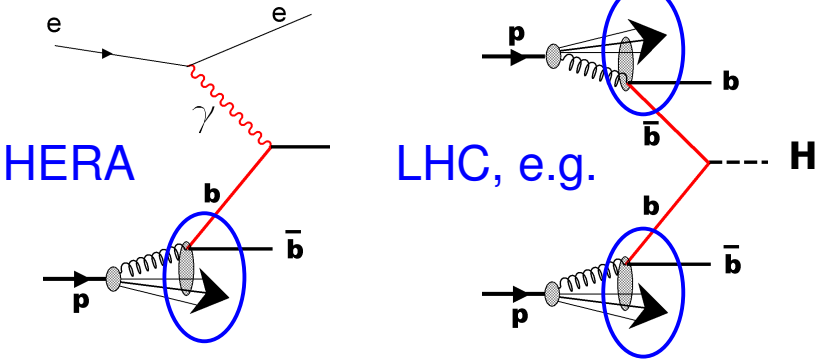


Beauty contribution to F_2



$F_2^{b\bar{b}}(x,Q^2)$

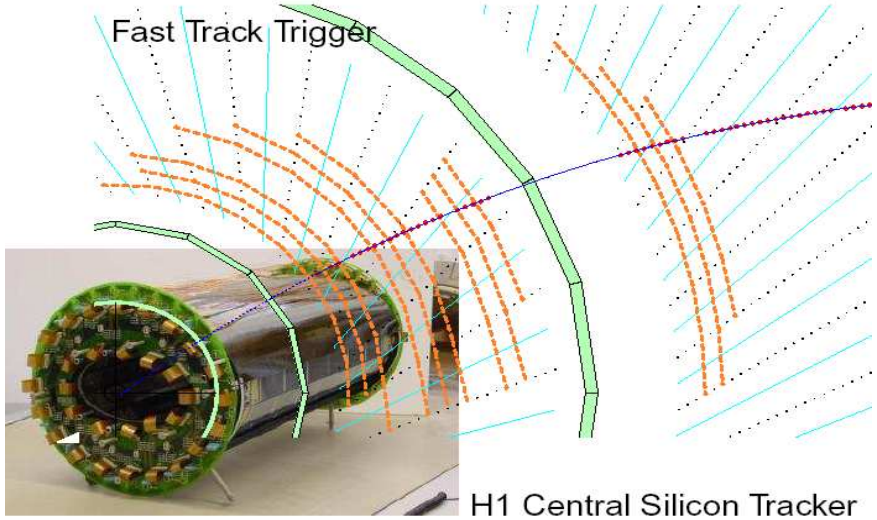
- first measurement
- rise with the gluon density (towards smaller x and larger Q^2)
- data are well described by calculations



Detector upgrades for HERA II

upgrades most relevant for heavy flavour production:

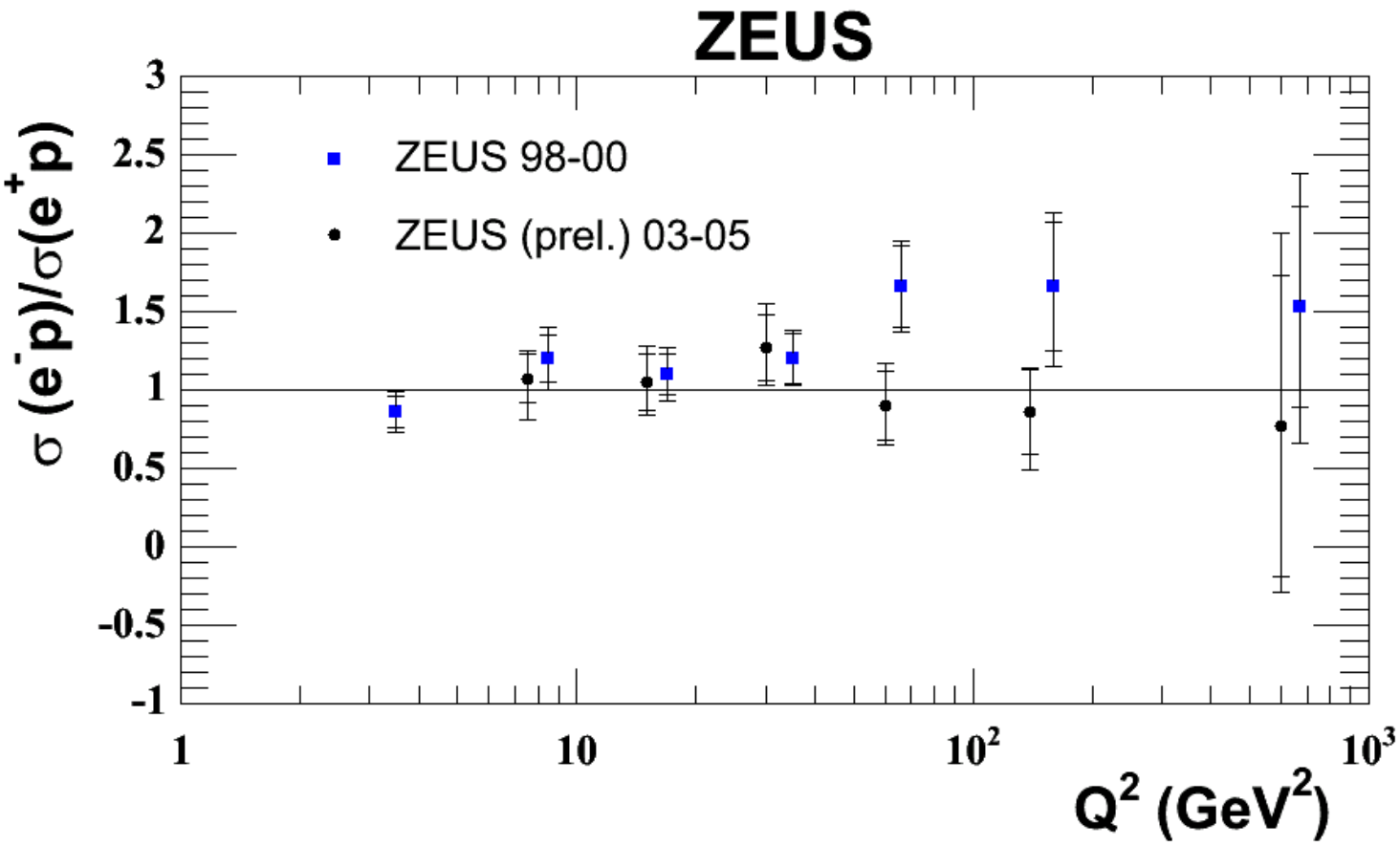
- H1 Fast Track Trigger



- ZEUS Micro-Vertex Detector (MVD)

Charm in HERA II data

first 30 pb^{-1} of HERA II data

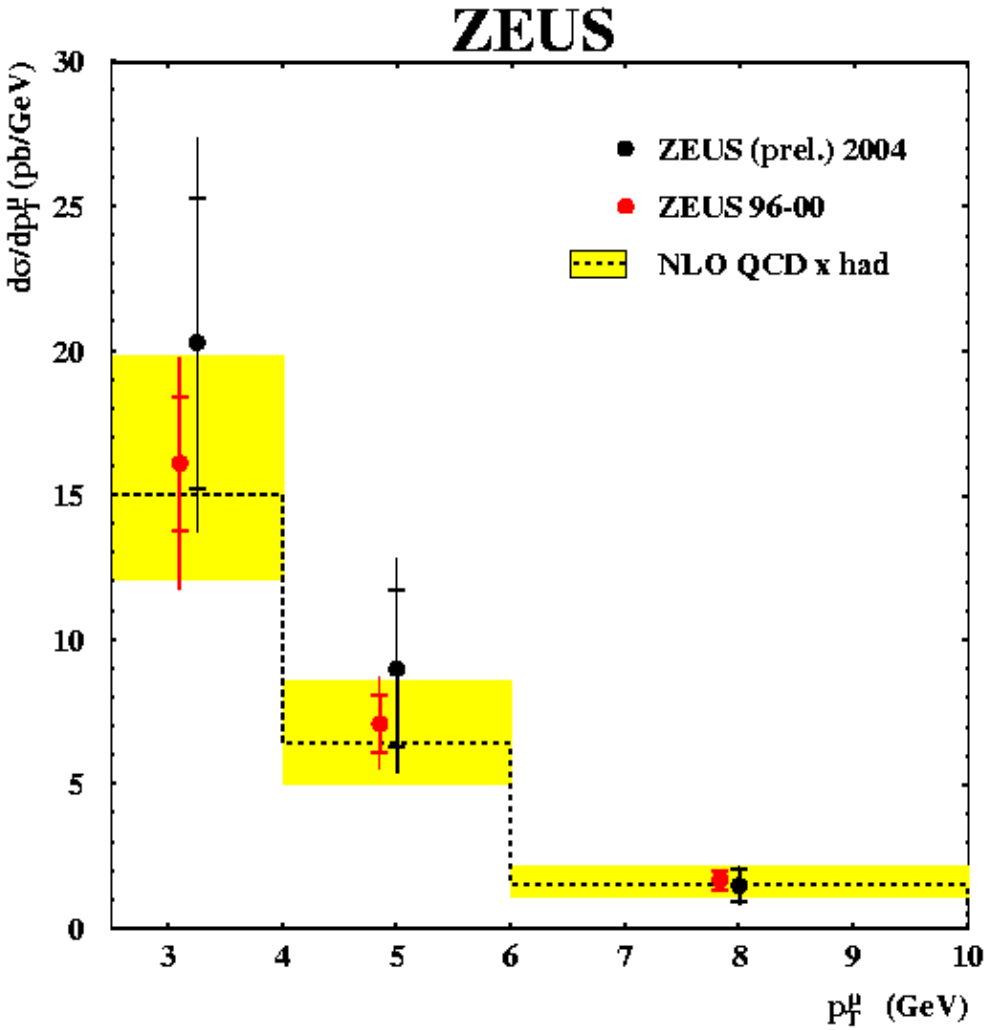


HERA I "excess" in charm e^-p/e^+p cross section at high Q^2 was statistical fluctuation (as expected)

Beauty in HERA II data

- First preliminary results using new ZEUS MVD:
  - first 30 pb^{-1} of HERA II data
  - combine muon p_t^{rel} with impact parameter (μ+dijet events)

- Outlook: improve by
  ~ order of magnitude and
  new double differential measurements possible

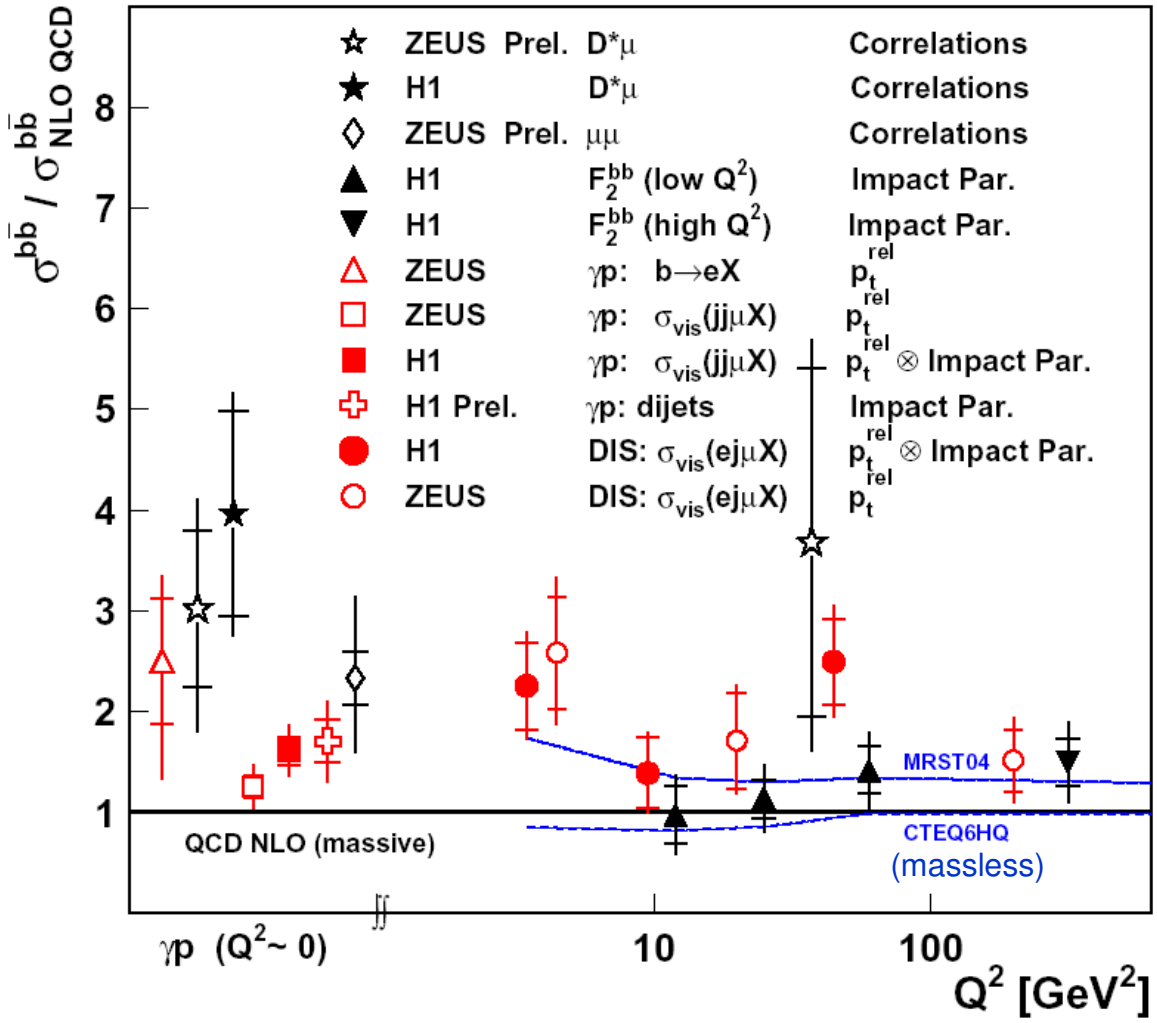


Summary and Conclusions

- Heavy Flavour production in *ep*-collisions remains interesting testing ground for perturbative QCD
- charm production:
  - high precision data are reasonably described by NLO QCD, in γp data are slightly higher than predictions
  - NNLO or NLO+PS needed for some regions of phase space (γp)
- beauty production:
  - reasonable description at high p_t^b getting worse (but still acceptable) at low p_t^b?
  - in DIS data tend to be higher than prediction (e.g. at low p_t, large η)
- Structure Functions ($F_2^{c\bar{c}}$, $F_2^{b\bar{b}}$):
  - both charm and beauty well described
  - first measurement of $F_2^{b\bar{b}}$
- HERA II performing well and most data are expected to come. Expect improved results soon!

BACKUP

Beauty cross sections vs. Q^2

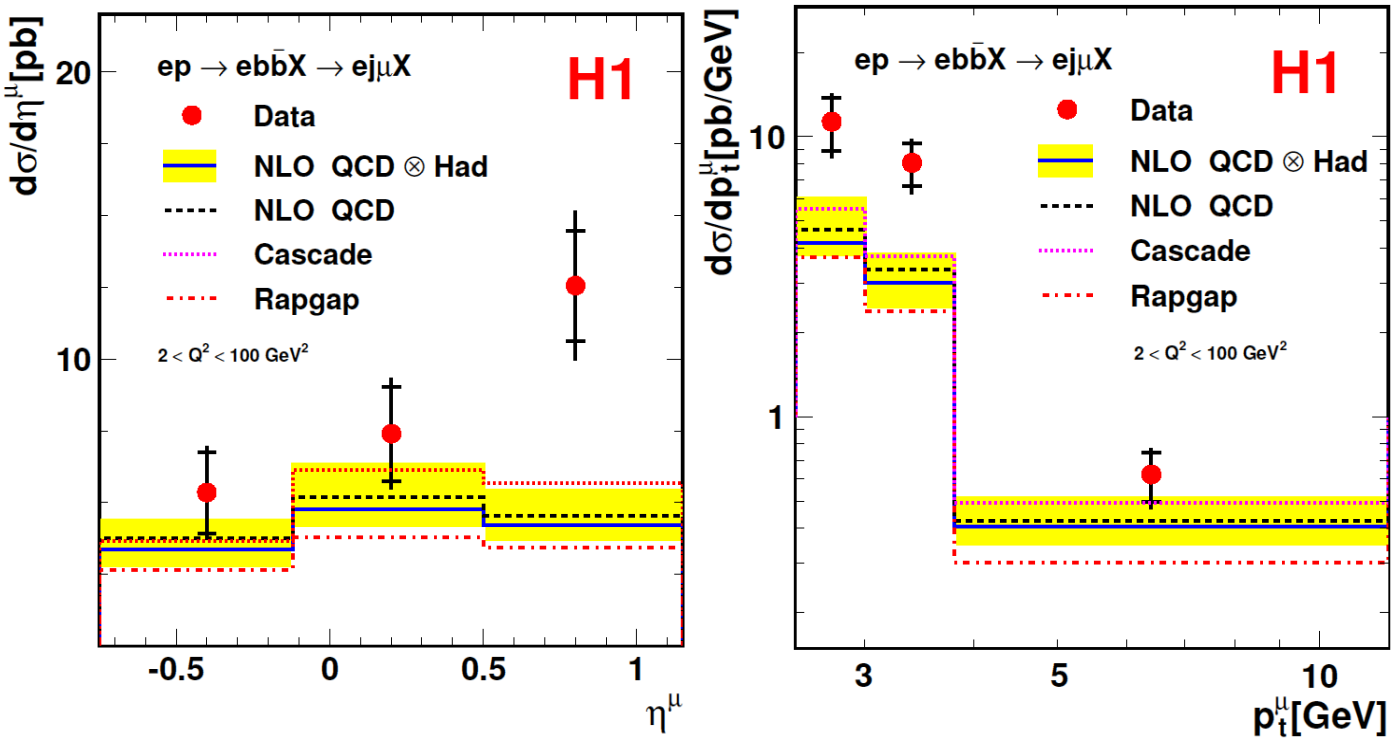


different p_{Tb} scales !

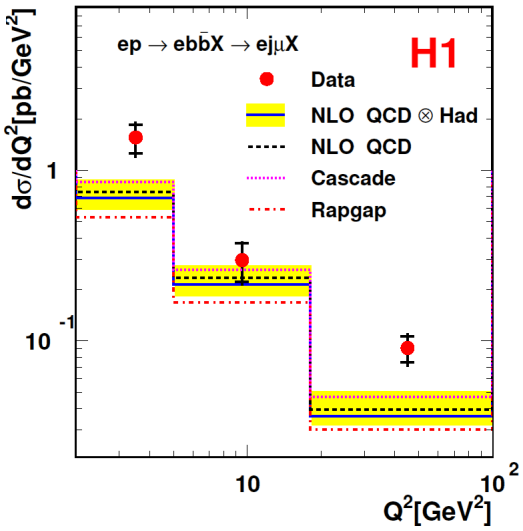
Key	Ref.	Signature	p_T cuts
Photoproduction			
◊	[18]	$\mu\mu$	low
☆	[19]	$D^*\mu$	low
★	[20]	$D^*\mu$	low
△	[21]	2 jets+e	medium
□	[22]	2 jets+μ	medium
■	[23]	2 jets+μ	medium
✚	[16]	tracks	high
DIS			
☆	[19]	$D^*\mu$	low
▲	[24]	tracks	low
▼	[17]	tracks	low
●	[23]	1 jet+μ	medium
○	[25]	1 jet+μ	medium

no clear trend

Beauty in DIS



Data higher at low p_T^{μ} as for the γp measurement.
Higher data also in forward η.

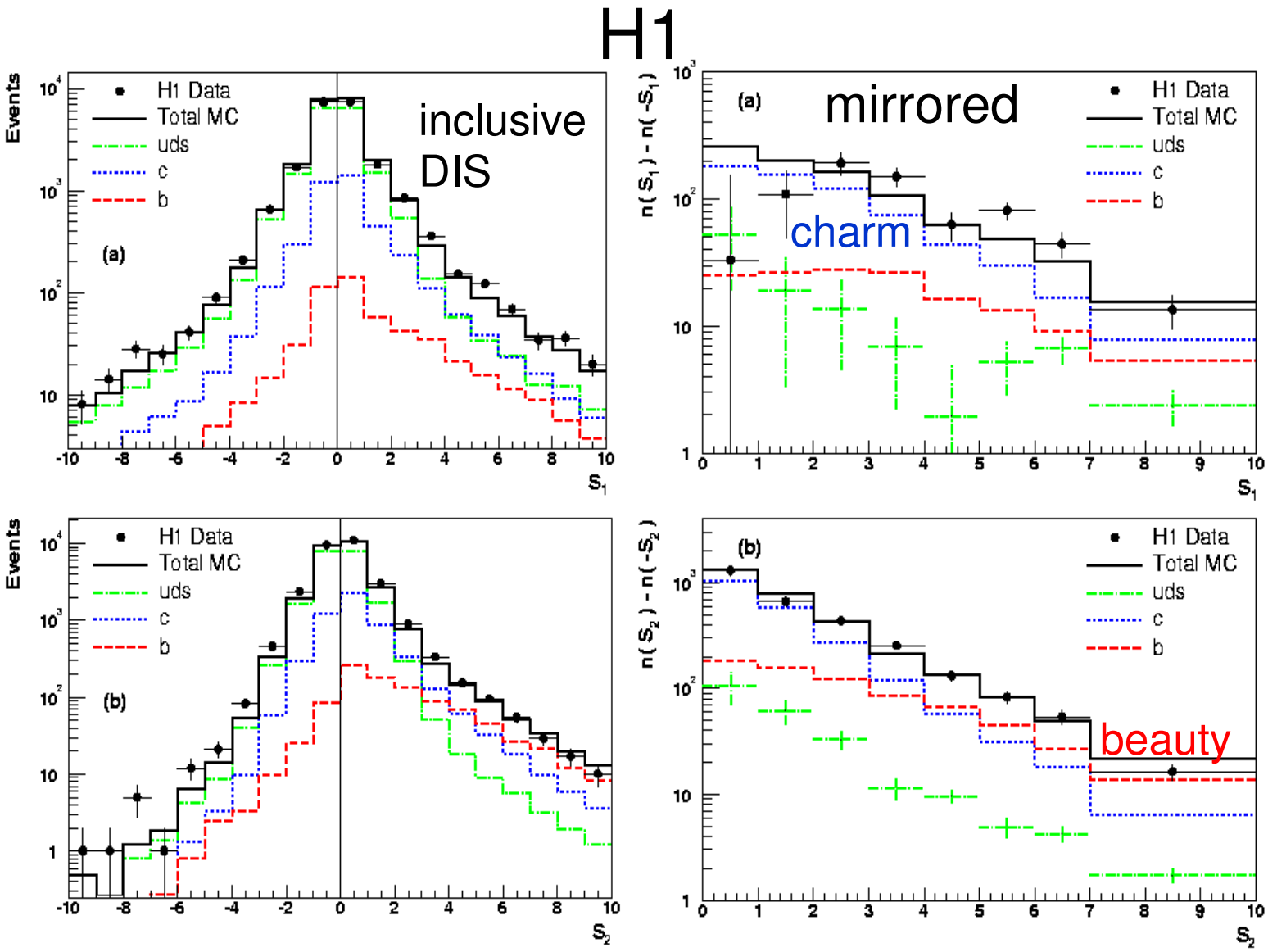


Q^2 shape is described, data slightly above the NLO prediction

Inclusive lifetime tags

most significant impact parameter S_1

2^{nd} most significant impact parameter S_2

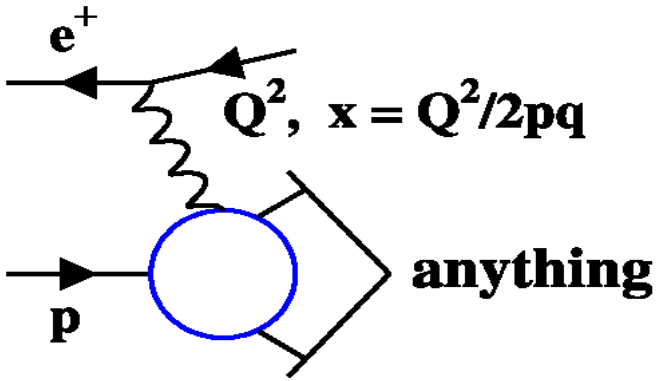


Contribution to the proton structure F_2

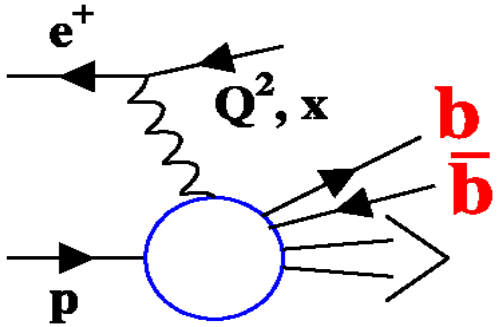
$$\frac{d^2\sigma}{dx\,dQ^2} = \frac{2\pi\alpha^2}{Q^4 x}\left\{\left[1+(1-y)^2\right]F_2(x,Q^2) - y^2 F_L(x,Q^2) + \ldots xF_3\right\}$$

~negligible

at high Q^2



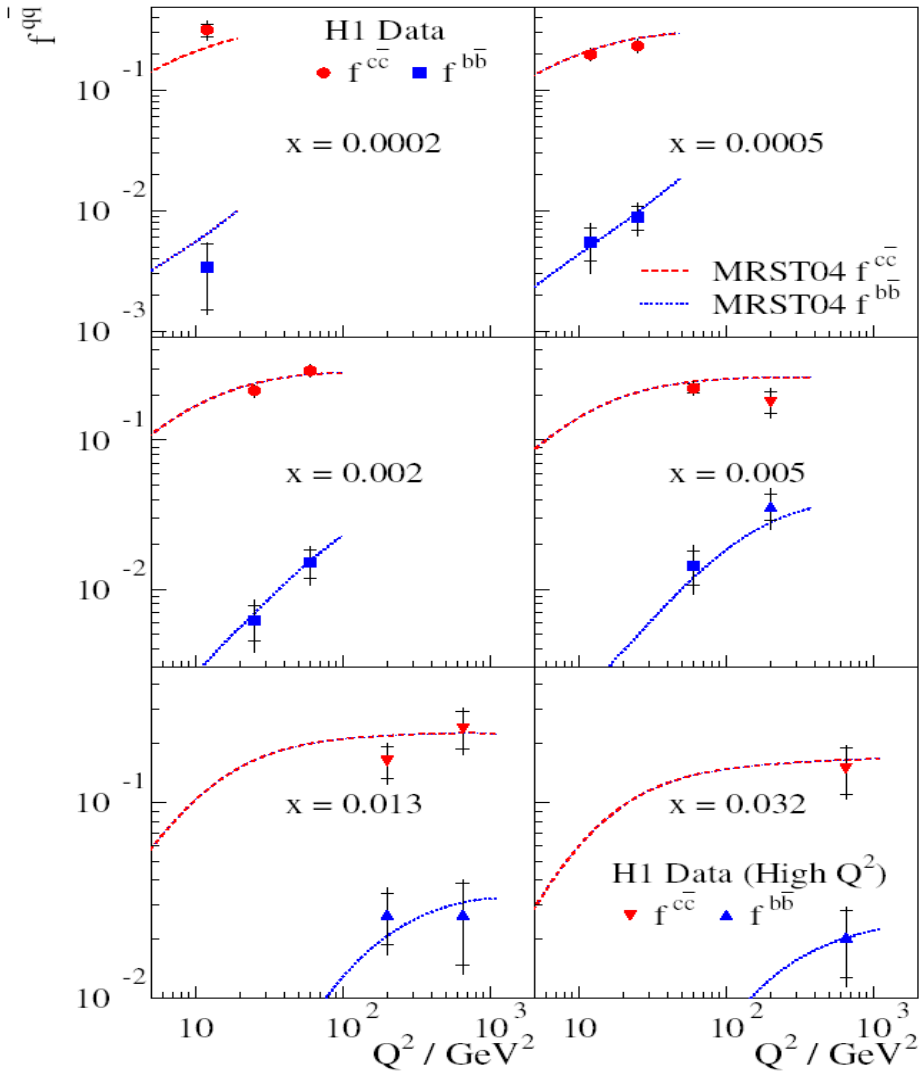
$$\frac{d^2\sigma^{ep}}{dQ^2dx} \propto F_2(x,Q^2)$$



$$\frac{d^2\sigma^{ep\to b\bar{b}X}}{dQ^2dx} \propto F_2^{b\bar{b}}(x,Q^2)$$

Inclusive lifetime tagging is used to determine fraction of $b\bar{b}$-events to all events

Comparison of *b* and *c* contributions



Fraction F_2^{bb}/F_2 and F_2^{cc}/F_2 in DIS

F_2^{bb} changes from permill-level (low Q^2) to percent-level (high Q^2)

pQCD approximations

Massive scheme:

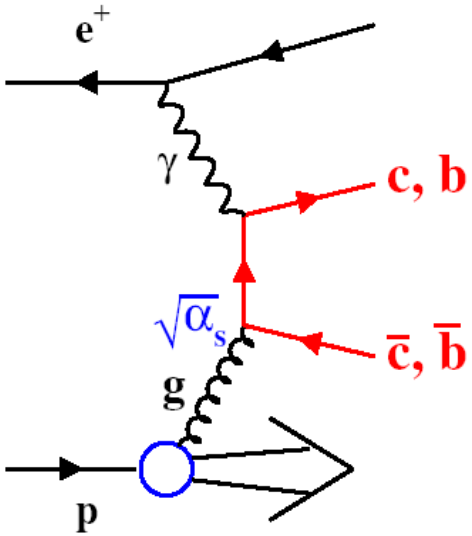
- *c,b* massive
- neglects $[\alpha_s \ln (Q^2/m_{c,b}^2)]^n$
- scale $m_{c,b}$

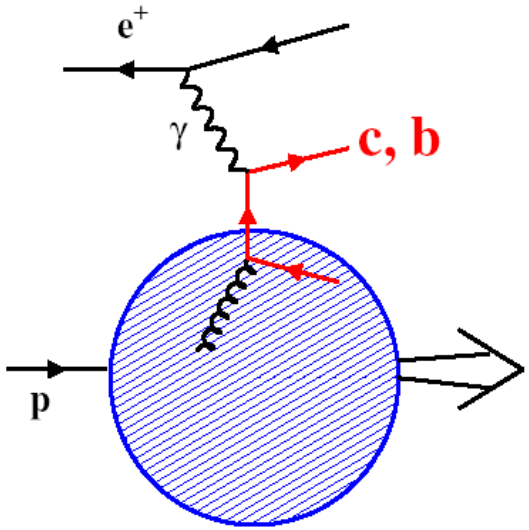
↳ *c,b* produced perturbatively (not part of the Proton or Photon)

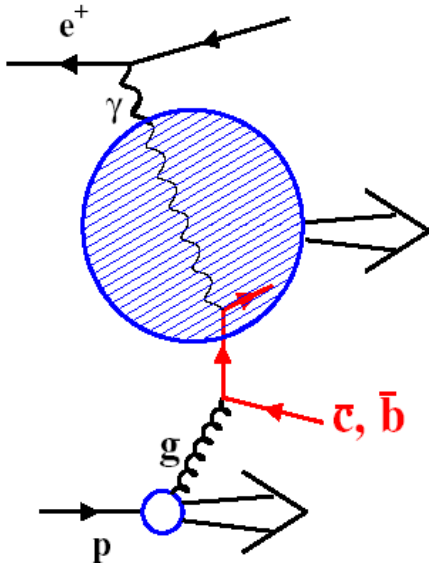
Massless scheme:

- *c,b* massless
- resums $[\alpha_s \ln (Q^2/m_{c,b}^2)]^n$
- scale: Q^2, p_t

↳ *c,b* also in Proton and Photon





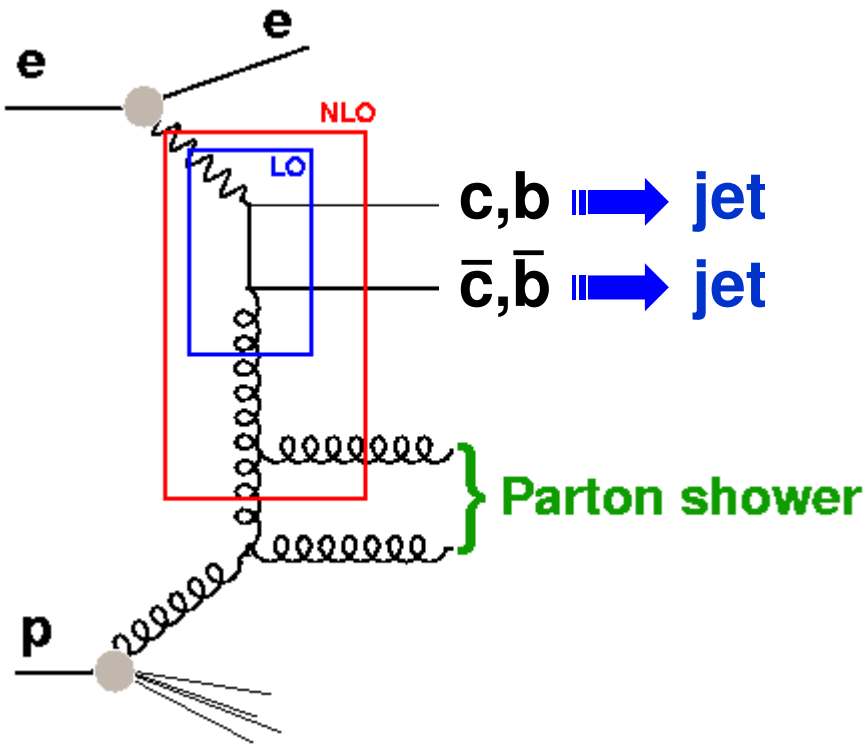


Variable flavour number scheme (VFNS):

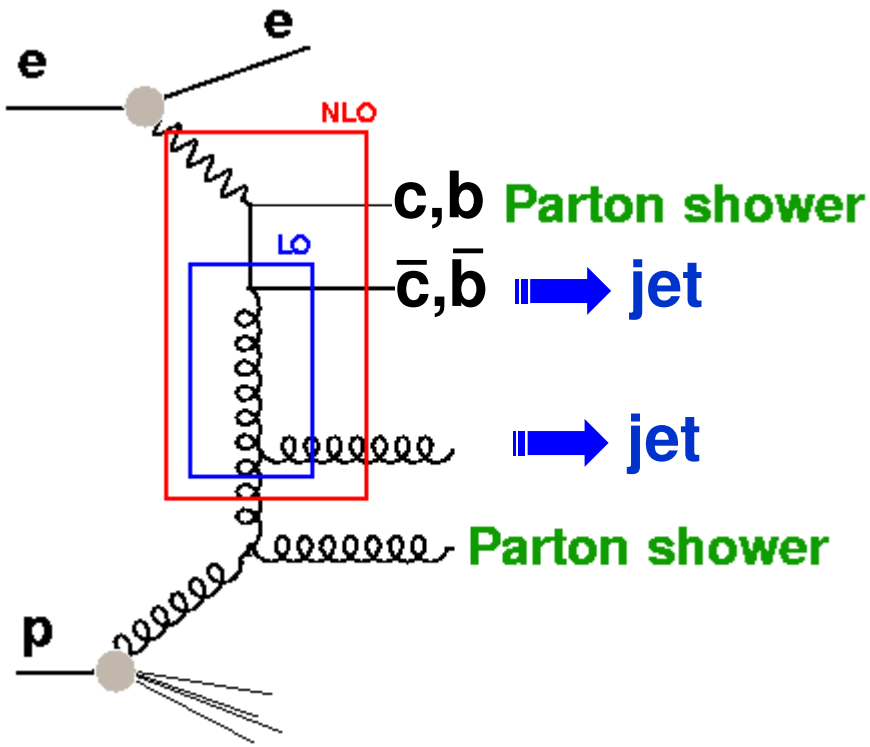
- massive at small Q^2
- massless at large Q^2

NLO vs. LO + parton shower

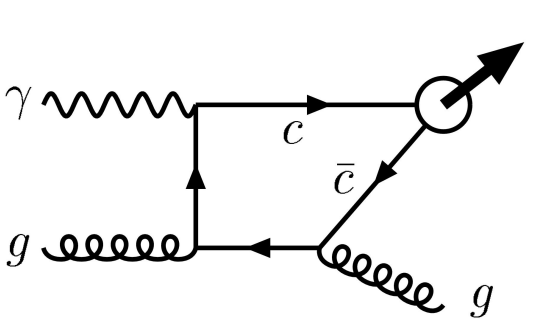
"direct γ"



"resolved γ"

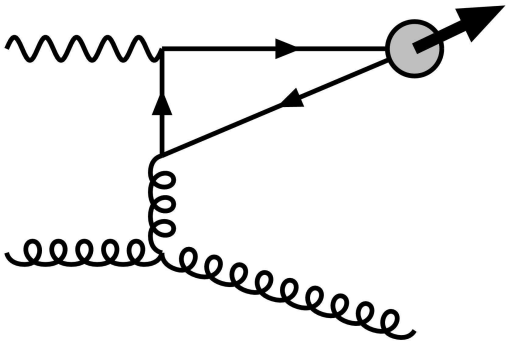


Inelastic J/ψ production



Colour Singlet (CS) contribution

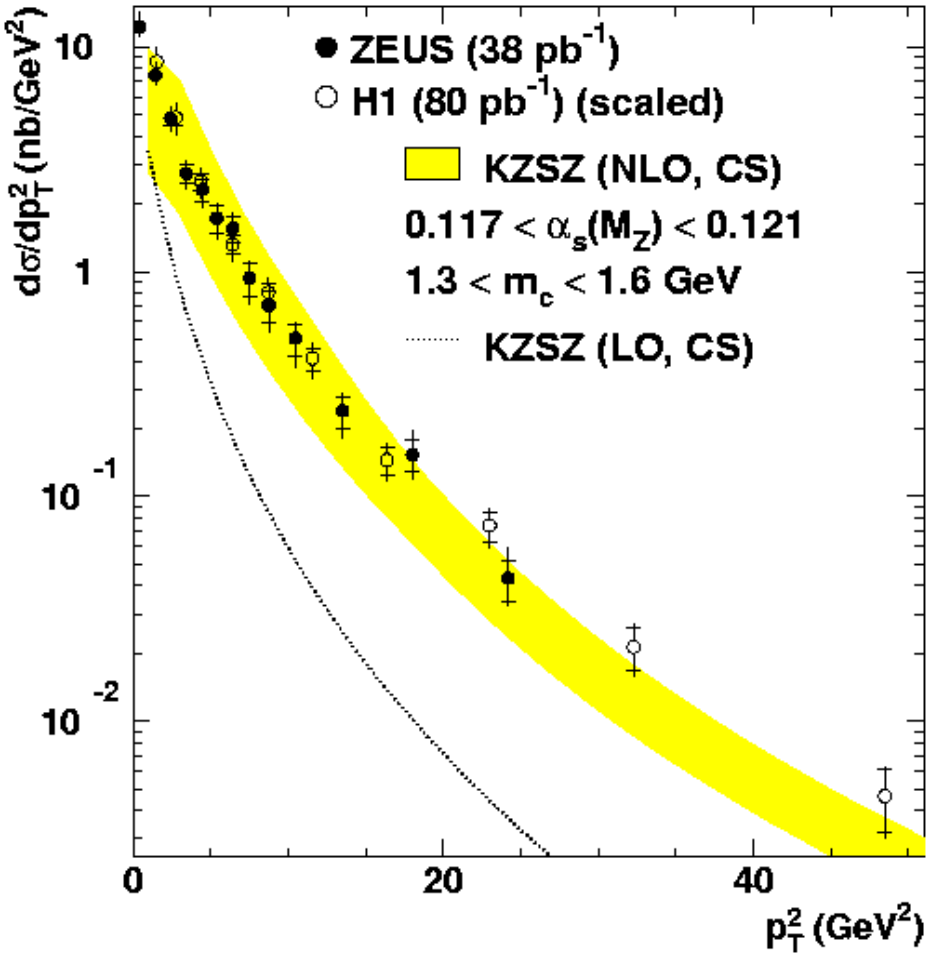
- directly calculable
- available at LO and NLO

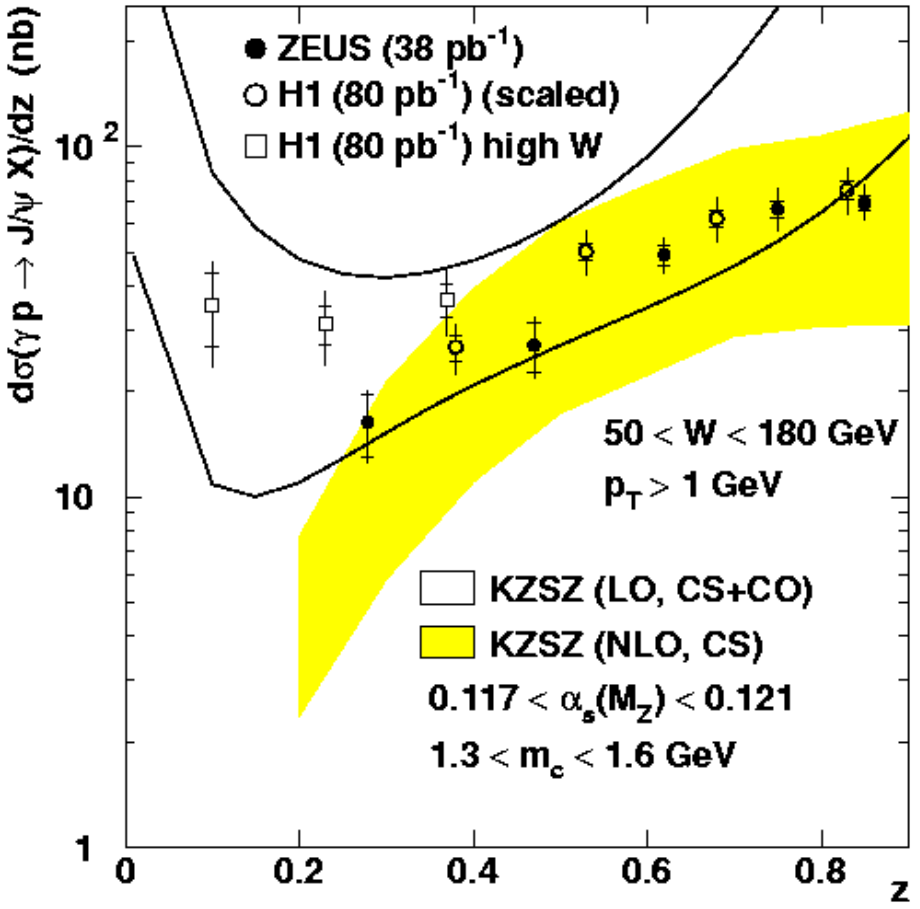


Colour Octet (CO) contribution

- introduced in NRQCD to describe Tevatron data
- not directly calculable
- parameterized from Tevatron
- prediction for HERA, LO only

Inelastic J/ψ in photoproduction

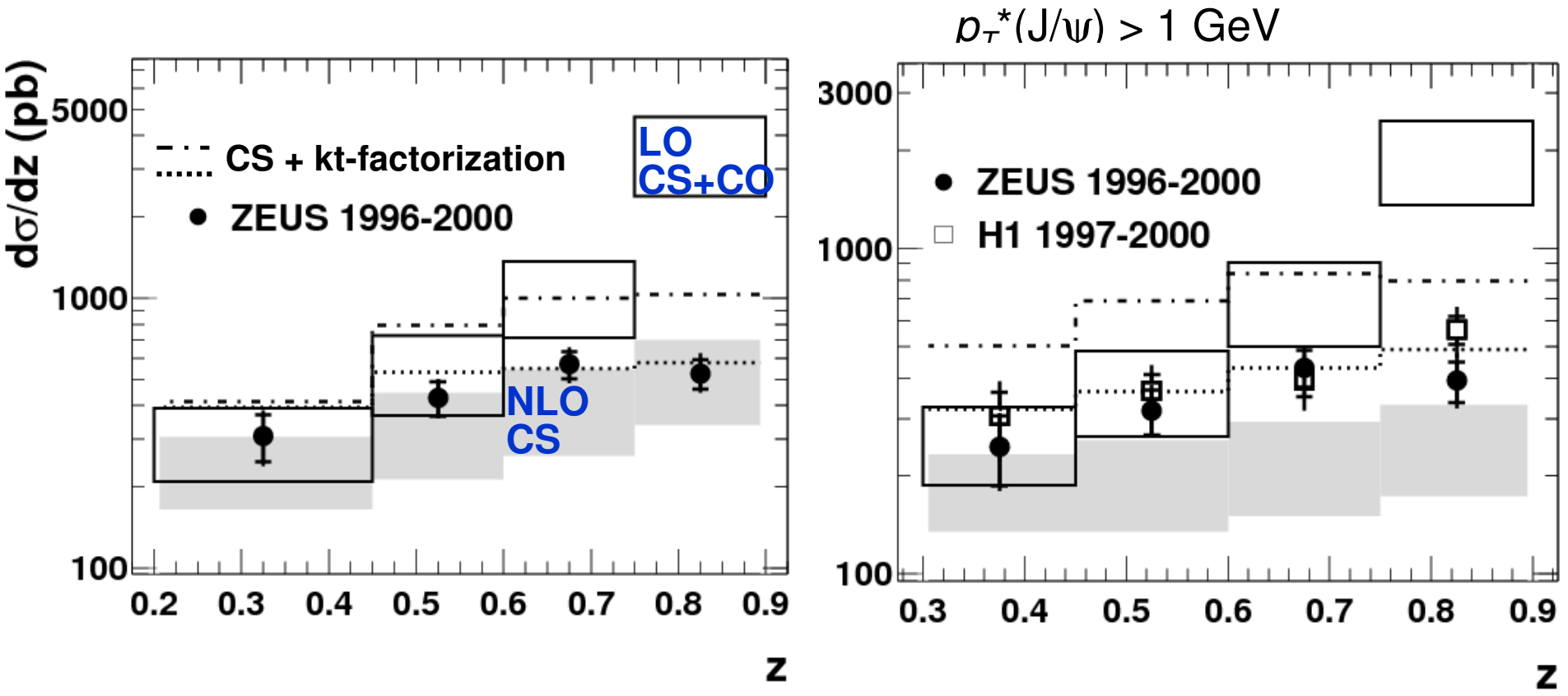




CS NLO/LO ~ factor 3-10!

z = fraction of γ energy carried by J/ψ (in p rest frame)

Inelastic J/ψ in DIS



Color Octet contribution not really needed to describe HERA data