Production of heavy flavours in ep collisions at HERA

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on behalf of the H1 and ZEUS Collaborations

Motivation

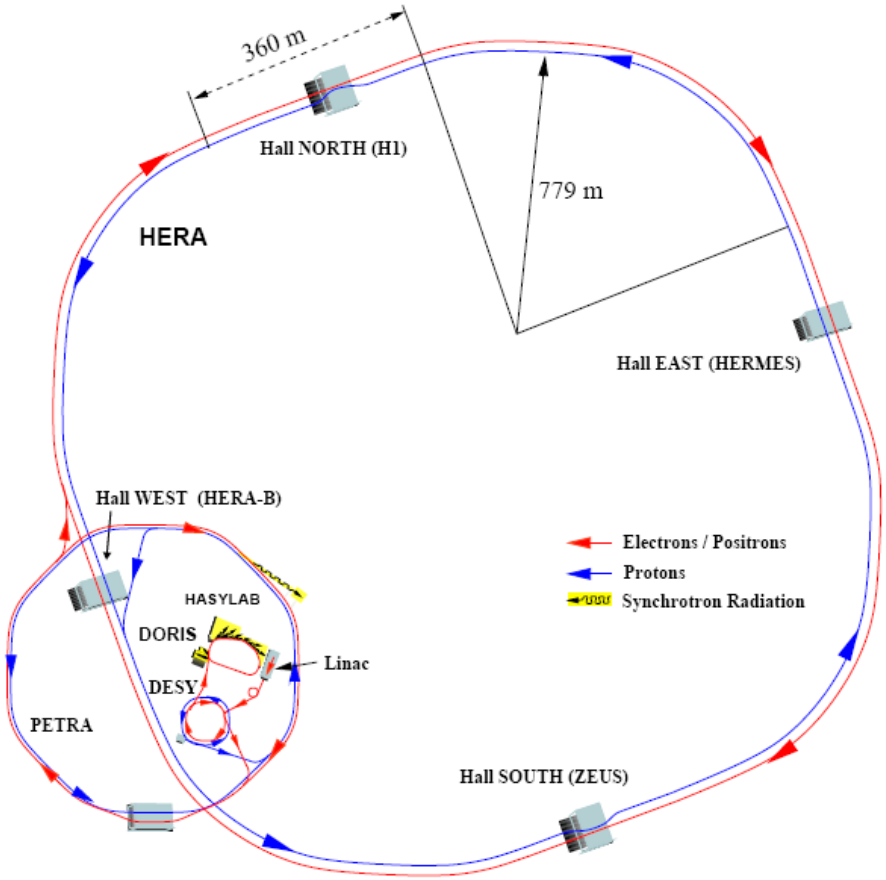
Predictions

Tagging methods

Tests of QCD in PhP and DIS

Structure Functions and PDF of Proton

The HERA Collider

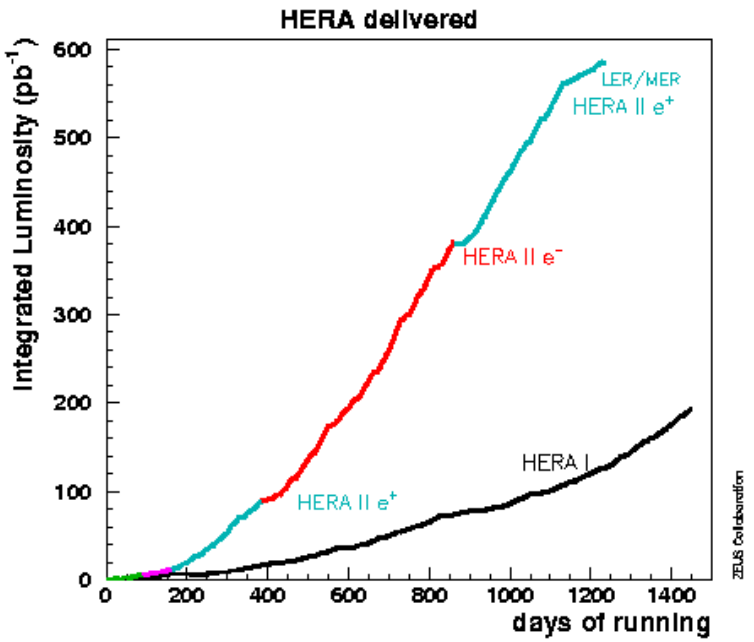


$e^{\pm}$ energy 27.5 GeV

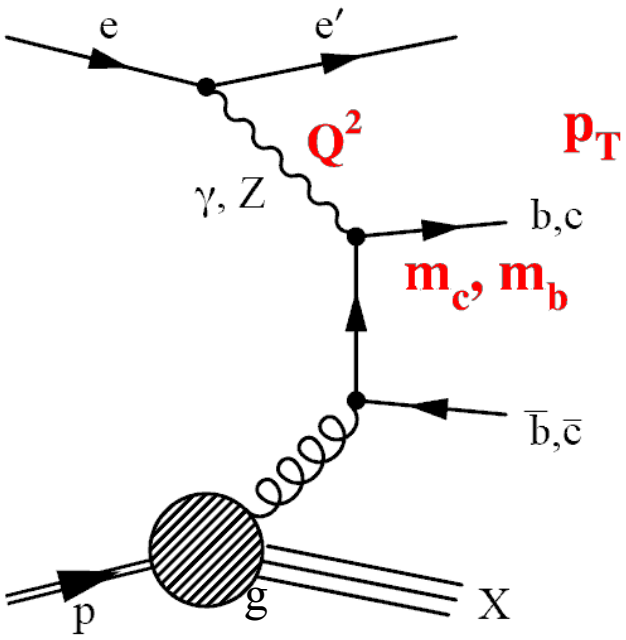
p energy 920 GeV

centre-of-mass energy 318 GeV

2 collider experiments: ZEUS and H1



Heavy Quark production in ep interactions

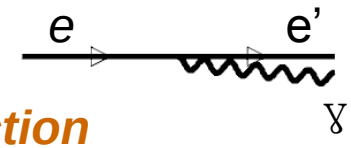


invariant kinematical variables:

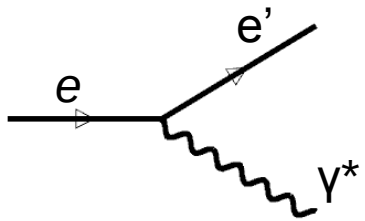
$s=(k+p)^2$	*center-of-mass energy of ep system squared*
$Q^2= -q^2=-(k-k')^2$	boson virtuality
$x=Q^2/2pq$	Bjorken scaling variable
$y=pq/pk$	inelasticity – fraction of lepton energy transferred to the hadronic system in the proton rest frame

Two kinematic regimes:

$Q^2 \approx 0$ GeV^2



Photoproduction



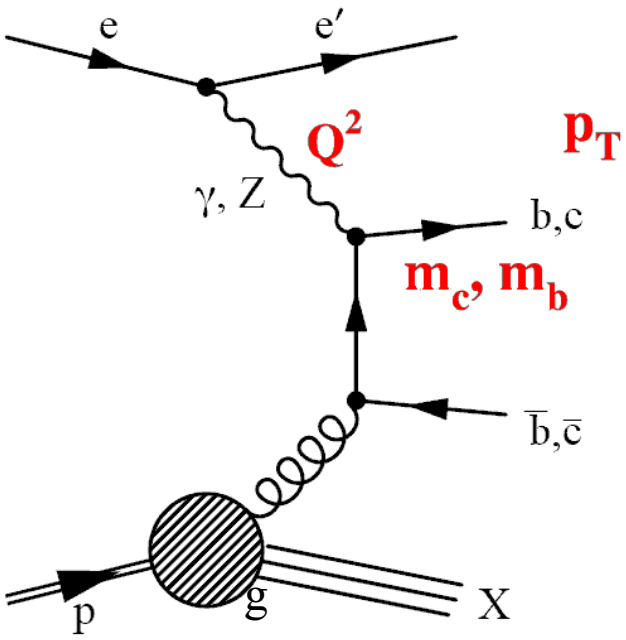
Q^2>1 GeV^2

Deep Inelasting Scattering

Boson Gluon Fusion (BGF)

dominating mechanism of heavy quark production

Motivation



c and b quarks provide a hard scale

-Tests of pQCD based models – scales Q^2, m_{HQ} ,p_T

BGF process is directly sensitive to the gluon density in the proton

-M*easurement of charm and beauty contribution to the structure function of the proton – F_2^{cc} and F_2^{bb} and their impact on the protons PDF*

pQCD calculations

Massive (FFNS)

c and b generated dynamically

c and b massive

Neglects $[\alpha_S \ln(\mu^2/m^2)]^n$

Valid for $\mu^2 \approx m^2$

Programs: HVQDIS, FMNR(PhP)

Massless (ZM-VFNS)

c and b massles partons in proton and photon

Resums $[\alpha_S \ln(\mu^2/m^2)]^n$

Valid for $\mu^2 >> m^2$

Variable Flavour Number Scheme (GM-VFNS)

Interpolation between massive and massless model

Massive at low Q^2

Massless at high Q^2

(eg. for prediction of F_2^{cc} and F_2^{bb})

Monte Carlo Generators

PYTHIA – most frequently used for PhP at HERA for all quark flavours
PS – according DGLAP approximation of the evolution of PDF
fragmentation – Lund string model

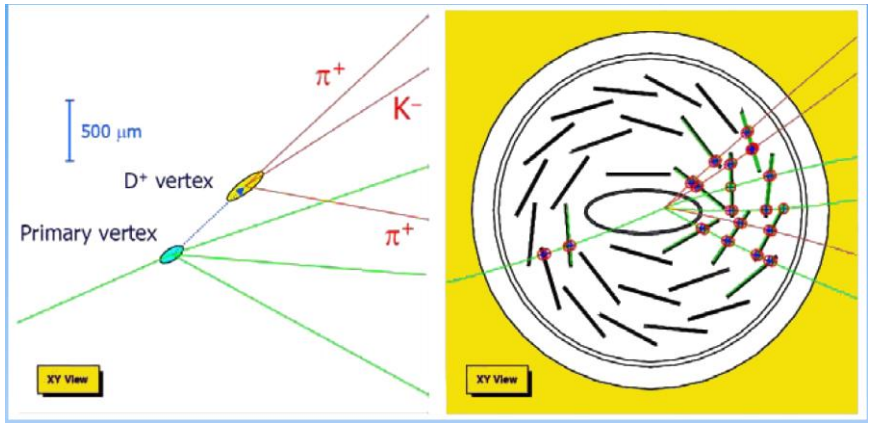
RAPGAP – standard event generator for DIS
HQ production in the massive scheme

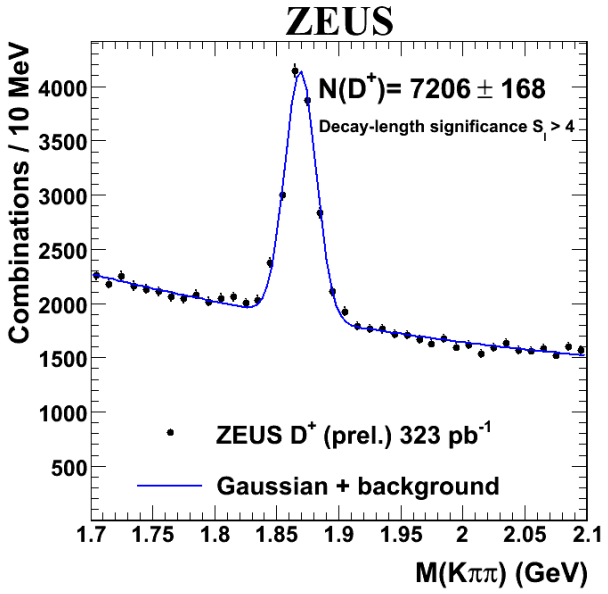
CASCADE – instead of DGLAP uses CCFM evolution equation
Can be used both for PhP and DIS

MC@NLO – NLO matrix elements for HQ production
PS and hadronisation from MC

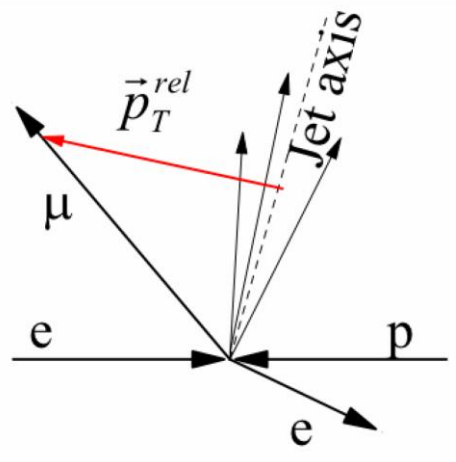
Heavy quark tagging methods

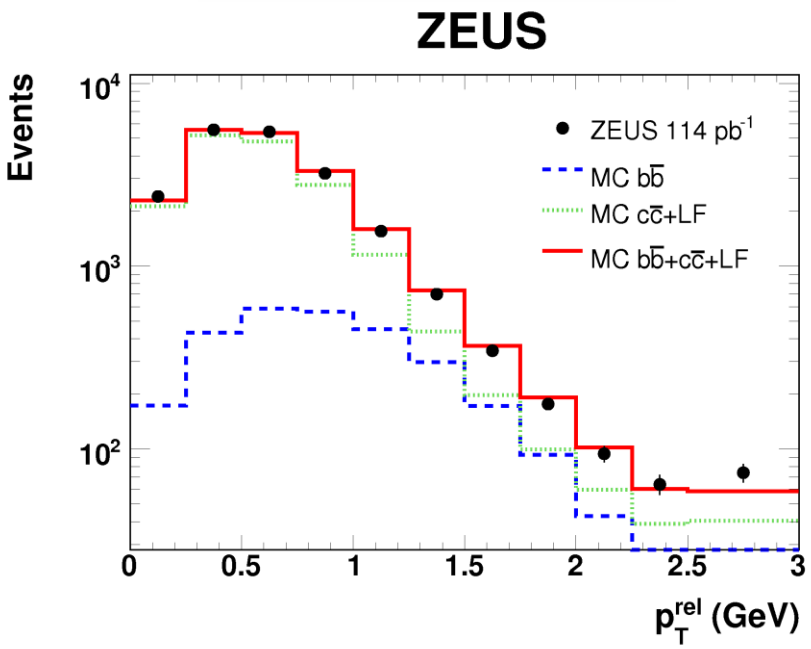
Reconstruction of D meson





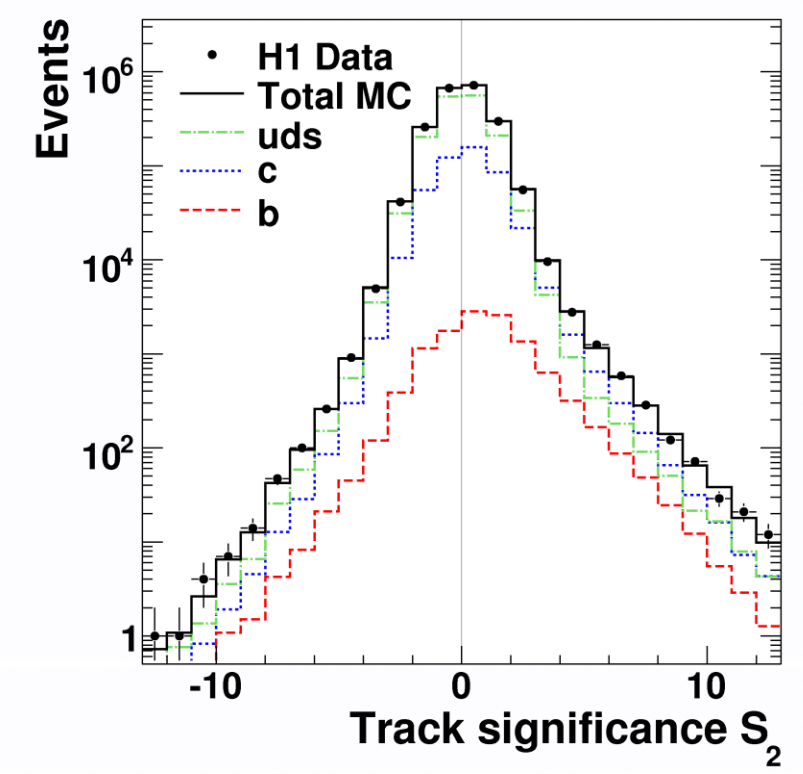
Semileptonic decay c,b→e or c,b→μ

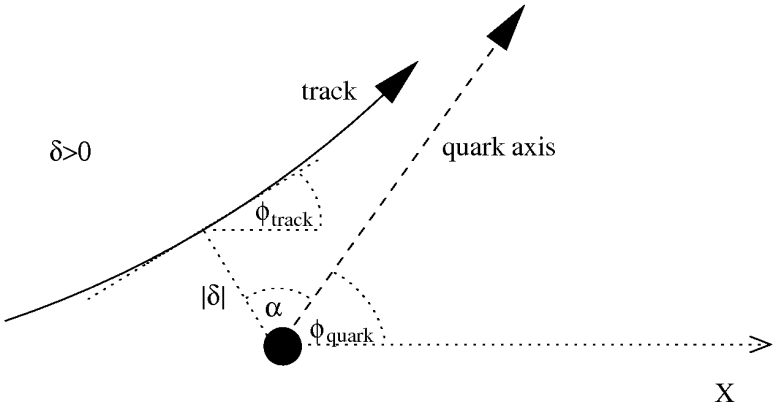


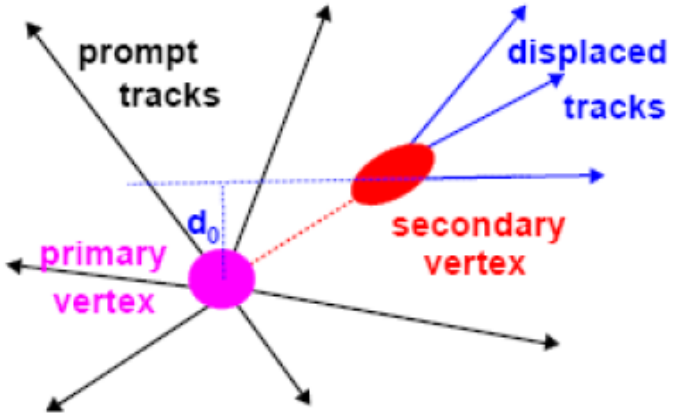


Heavy quark tagging methods

Inclusive method based on information from vertex detector and using long B and D lifetime



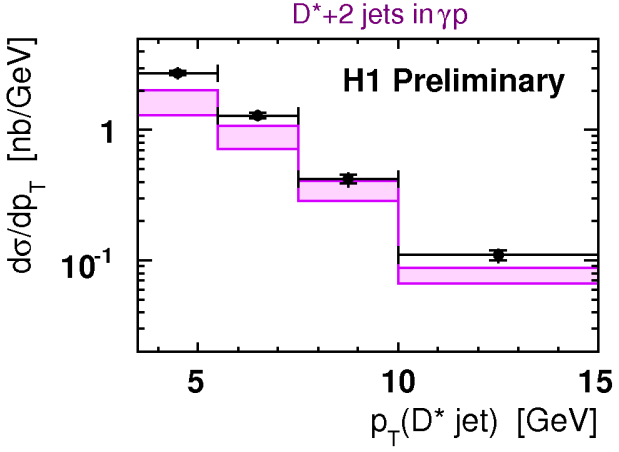


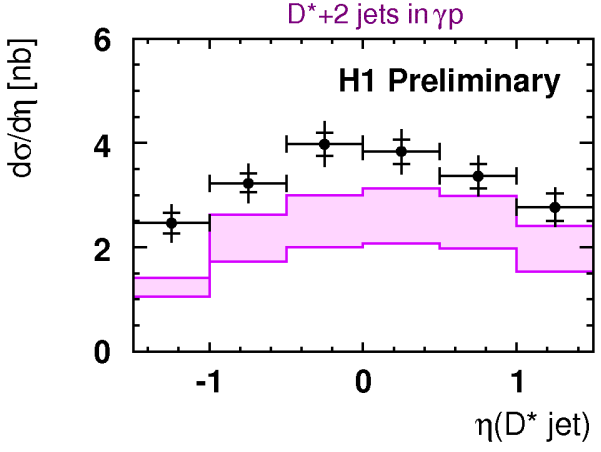


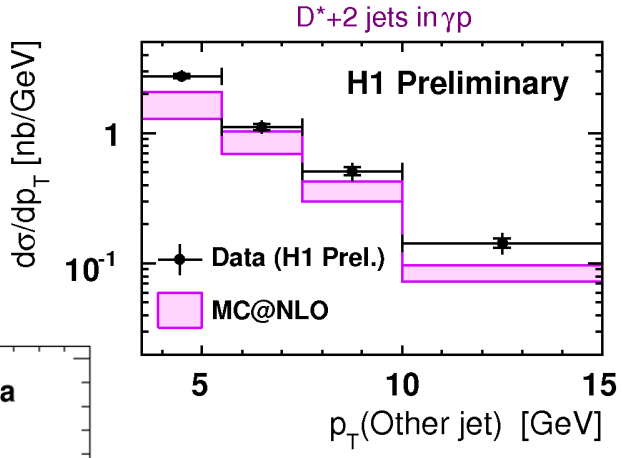
Charm ***Photoproduction*** using D* and dijets

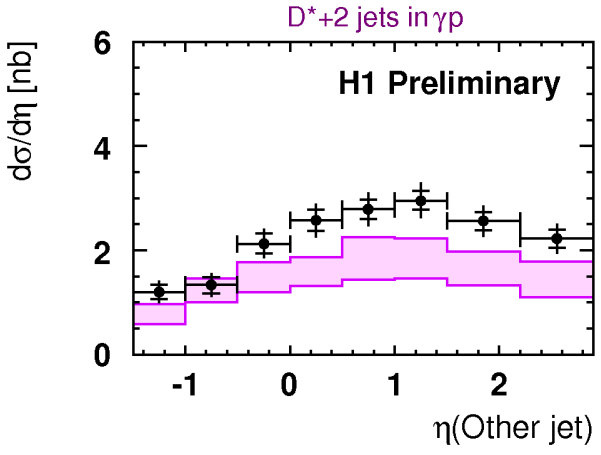
data sample: 93.4 pb^{-1}

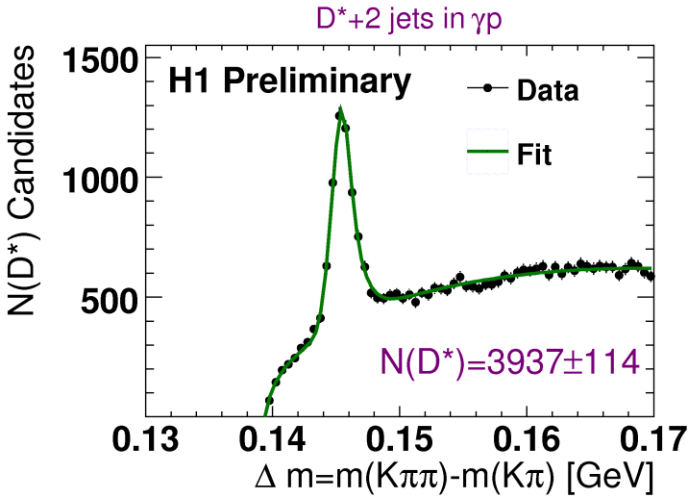
$Q^2<2$ GeV^2
D* reconstructed in the golden decay channel
$D^{*\pm}\rightarrow D^0\pi^\pm\rightarrow(K\pi)\ \pi^\pm$
$p_t(D^*)>2.1$ GeV
$|\eta(D^*)|<1.5$
$P_T^{jet}>3.5$ GeV









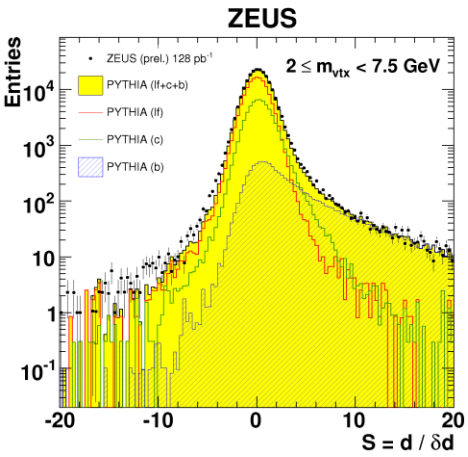


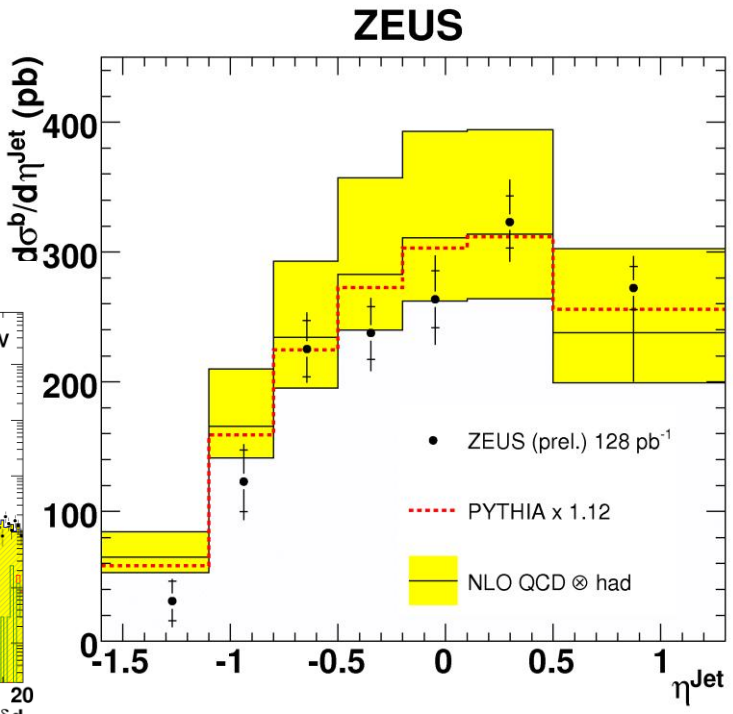
Reasonable agreement with MC@NLO

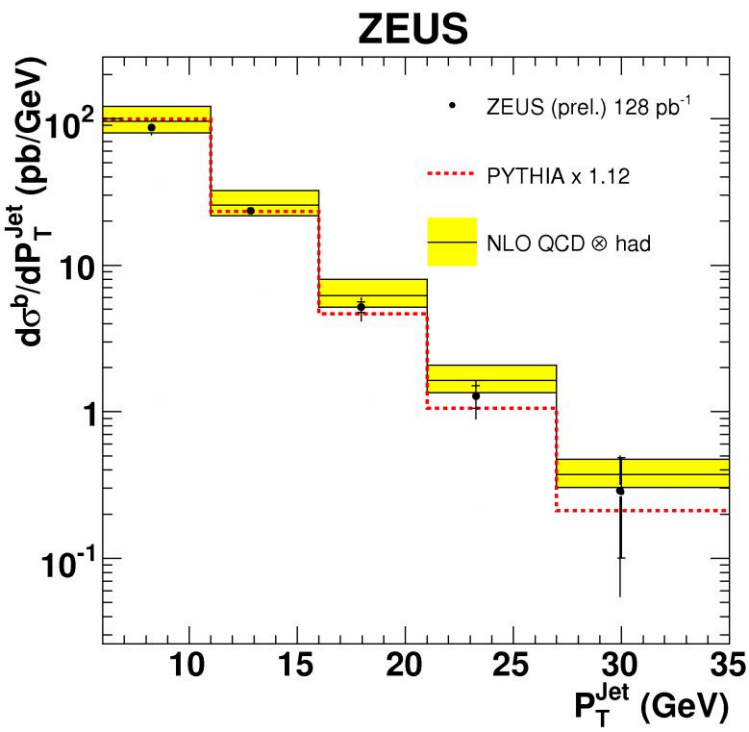
Beauty in Photoproduction with jets

data sample: 128 pb^{-1} (2006-07)

$Q^2<1GeV^2$
2 jets with
$p_T>7(6)$ *GeV*
$|\eta^{jet}|<2.5$





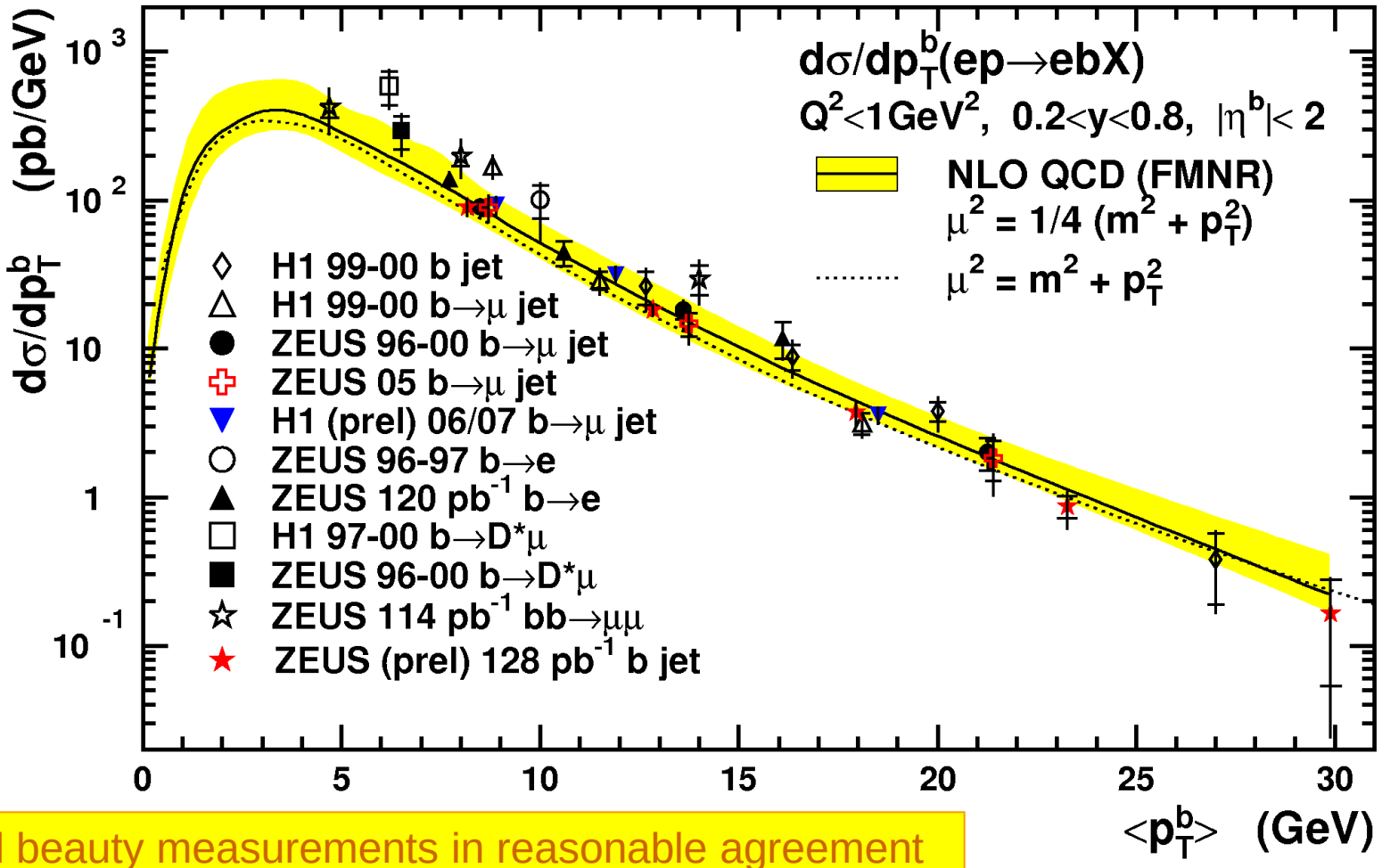


3D secondary vertices reconstructed using secondary vertex information

Good agreement with NLO

Beauty in Photoproduction with jets

HERA

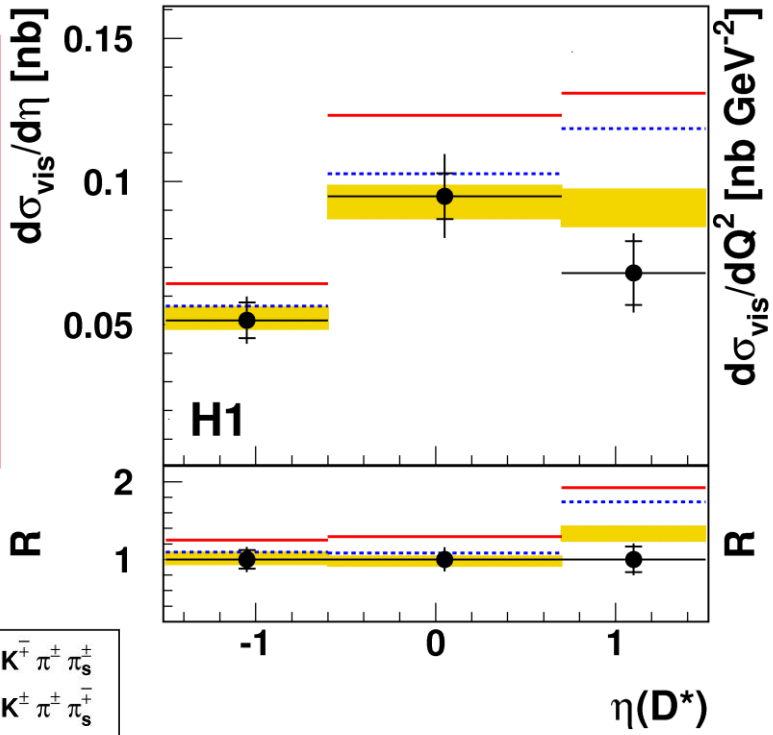


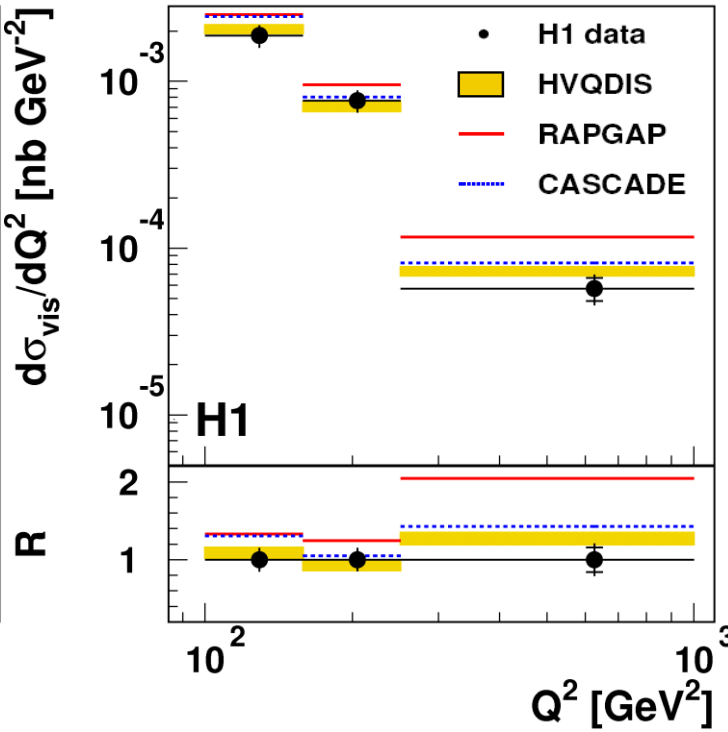
All beauty measurements in reasonable agreement
NLO prediction agrees with measurements
New measurement compatible with previous results

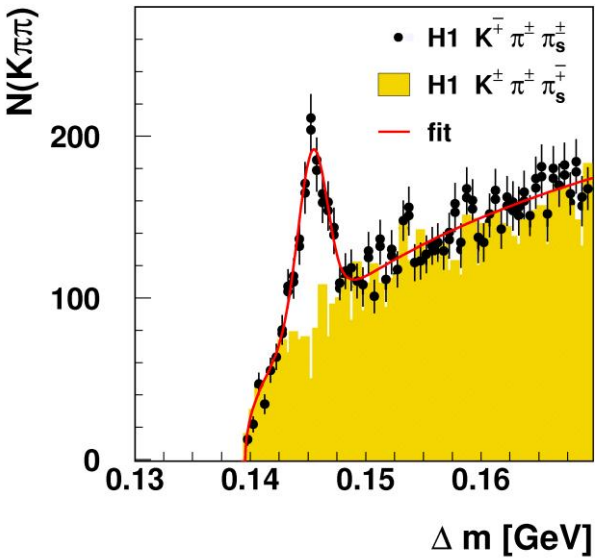
D* production in ***DIS*** at Q^2>100 GeV^2

data sample: 351 pb^{-1}

$100<Q^2<1000$ GeV^2
D reconstructed in the golden decay channel*
$D^{*\pm}\rightarrow D^0\pi^\pm\rightarrow(K\pi)\,\pi^\pm$
$p_T(D^*)>1.5$ GeV
$|\eta(D^*)|<1.5$
$0.02<y<0.7$

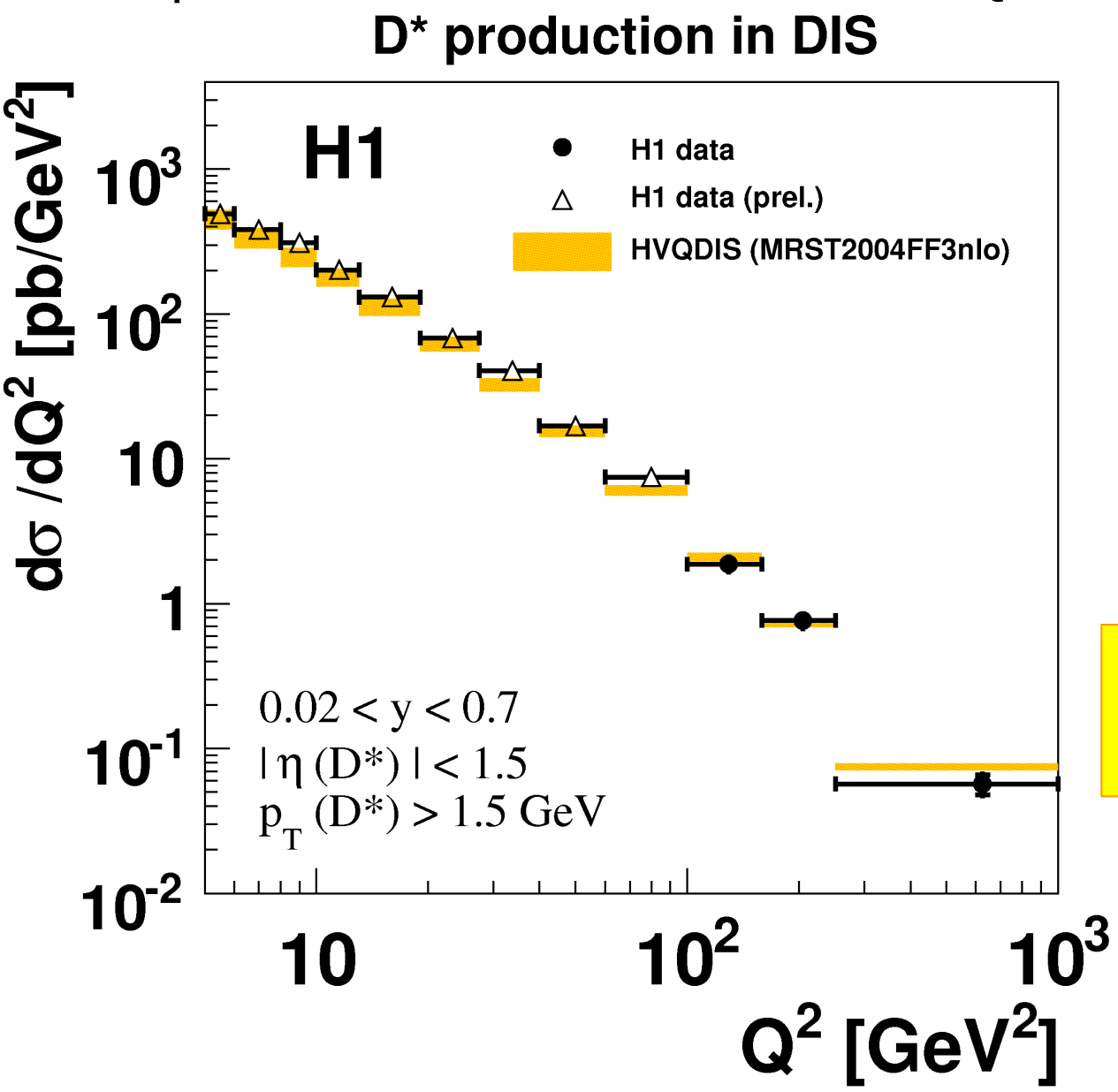






Good agreement with massive NLO (despite $Q^2>>m_c^2$)
MC LO predictions do not describe data well

D* production Cross Section in full Q^2 Range

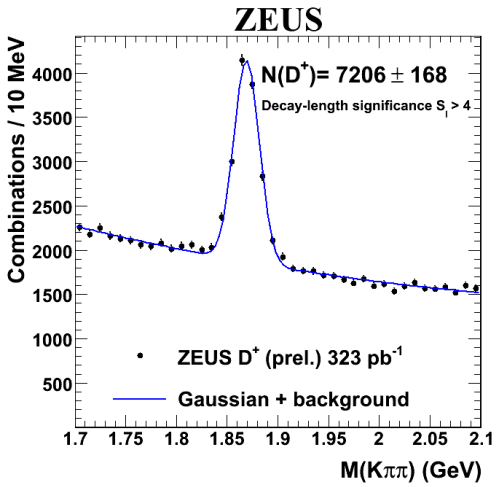


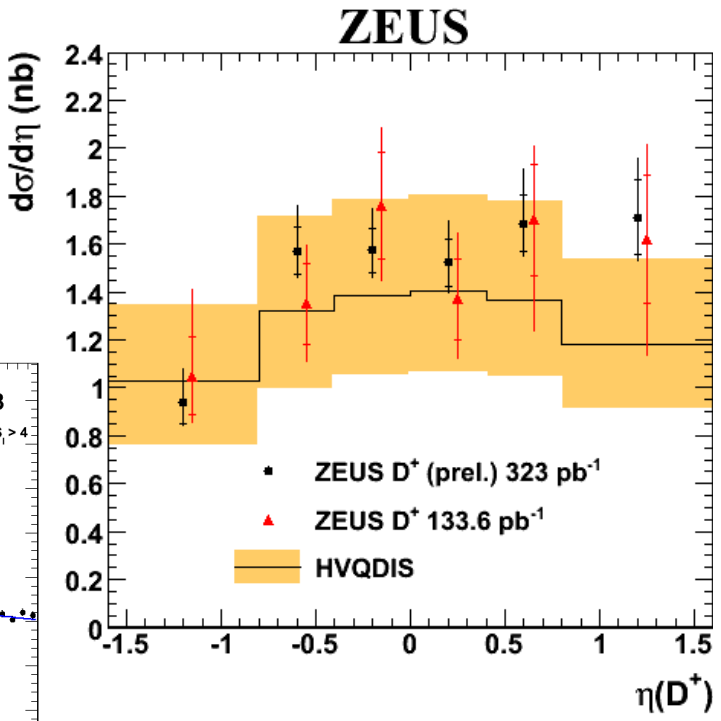
HVQDIS – describes data for whole kinematic region

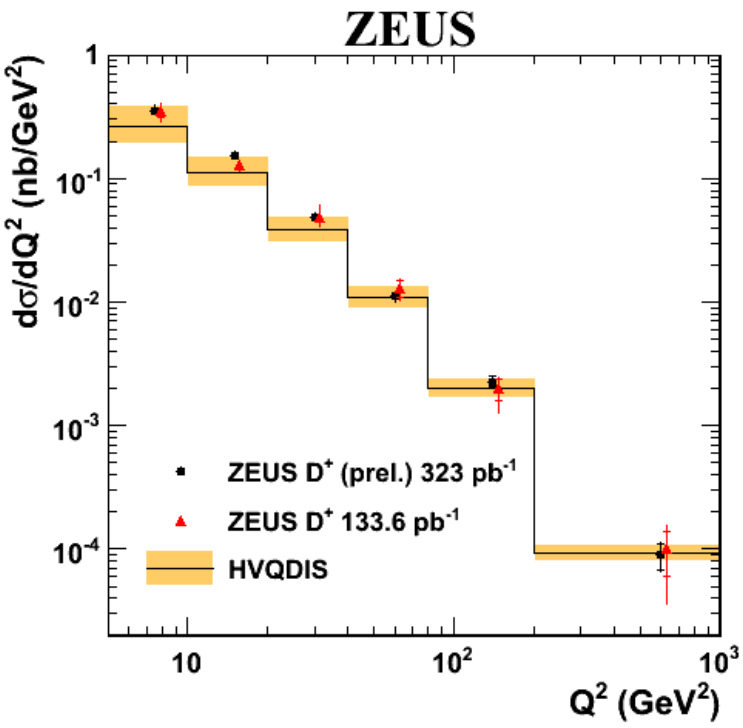
$D^{\pm}$ in DIS

data sample: 323 pb^{-1} (2005 -07)

$5<Q^2<1000$ GeV^2
$0.02<y<0.7$
$1.5<p_T(D^+)<15$ GeV
$-1.6<\eta^{jet}<1.6$





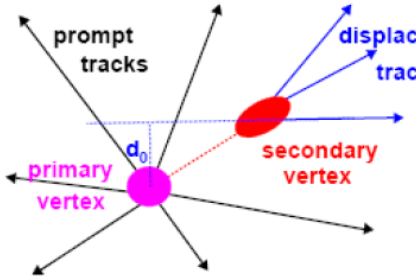


Reduction of background using secondary vertex information

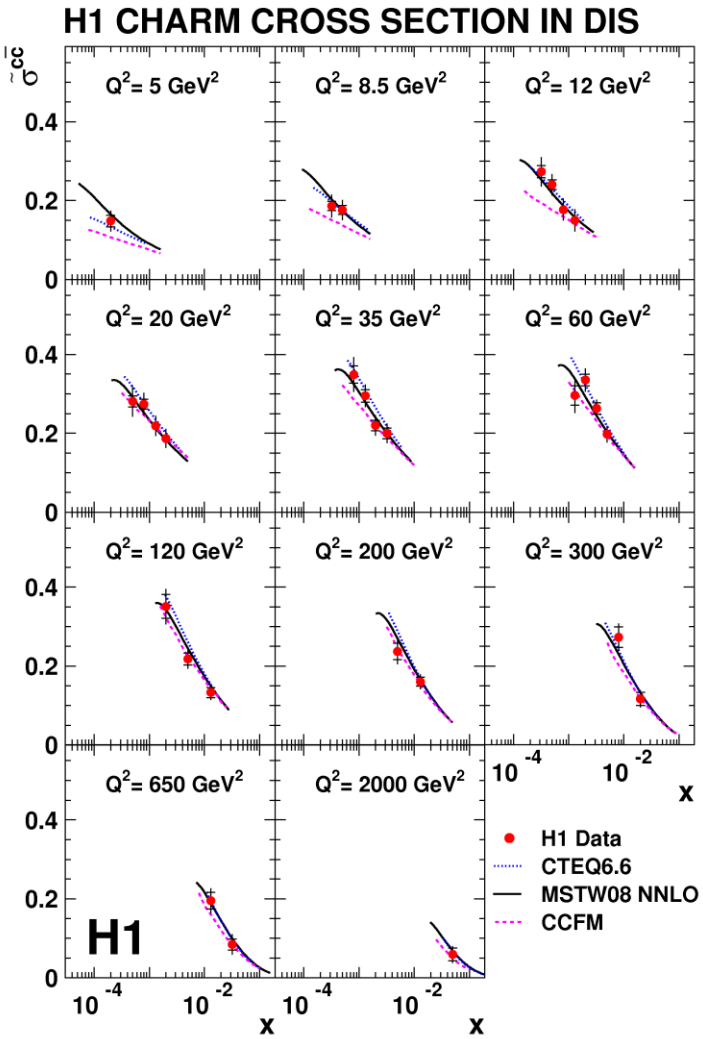
Good agreement with HVQDIS NLO QCD

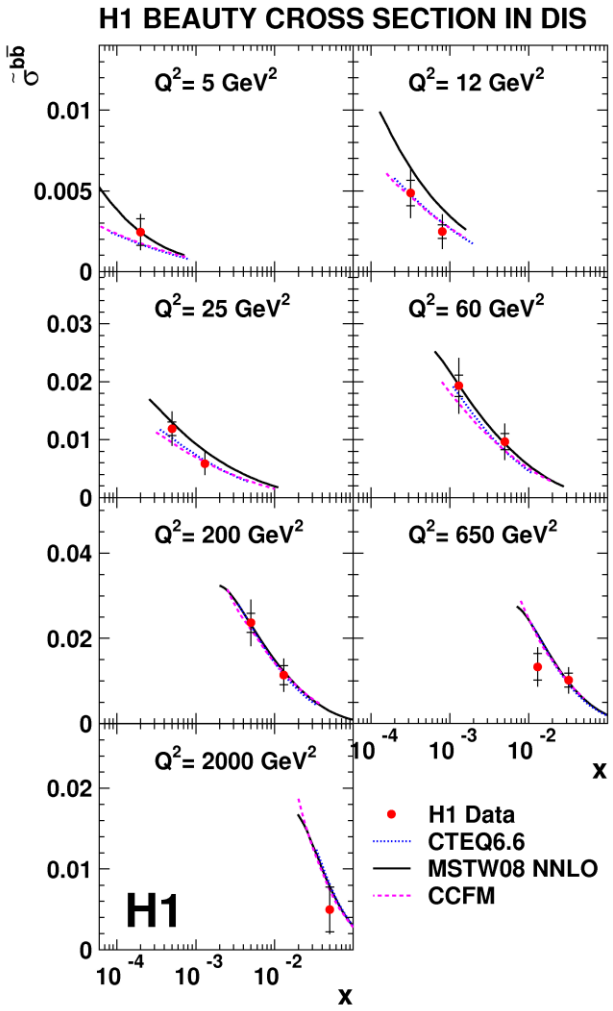
Inclusive charm & beauty in DIS

data sample:
189 pb^{-1} (2006-07)



Measurement using VTX detector





Predictions reasonably describe the data

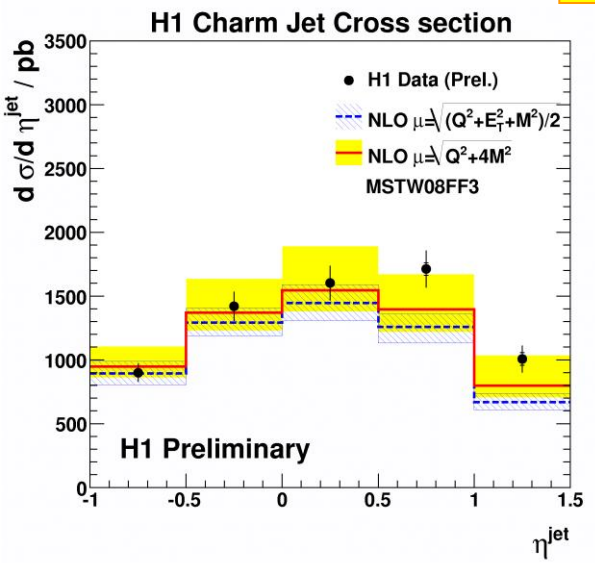
$$\tilde{\sigma}^{c\bar{c}}(x,Q^2) = \frac{\mathrm{d}^2\sigma^{c\bar{c}}}{\mathrm{d}x\,\mathrm{d}Q^2}\frac{xQ^4}{2\pi\alpha^2(1+(1-y)^2)}$$

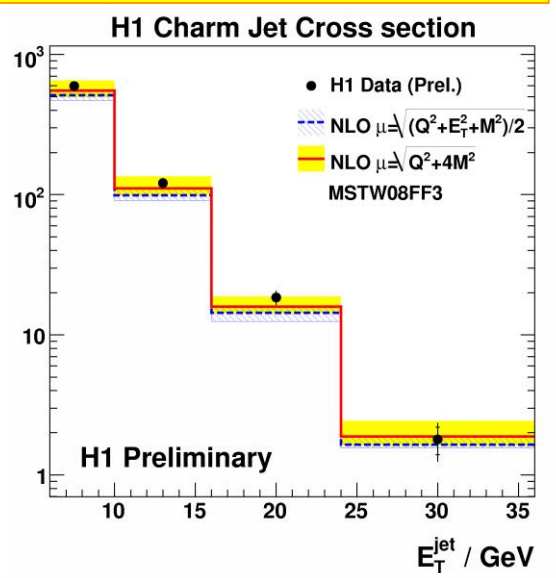
charm & beauty in DIS with Jets

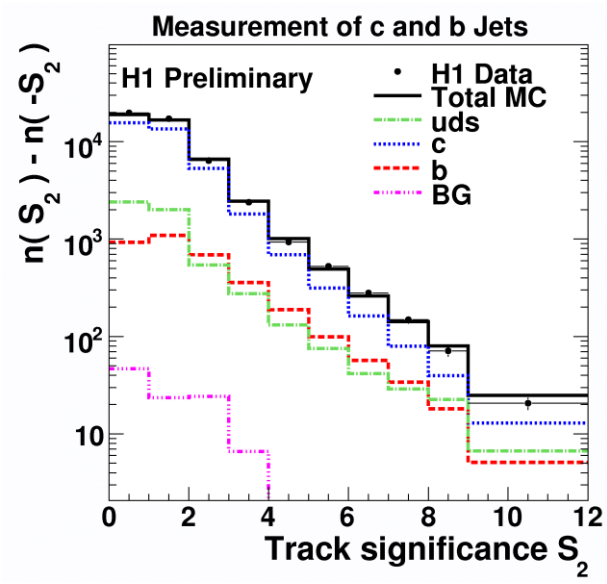
Good agreement with NLO

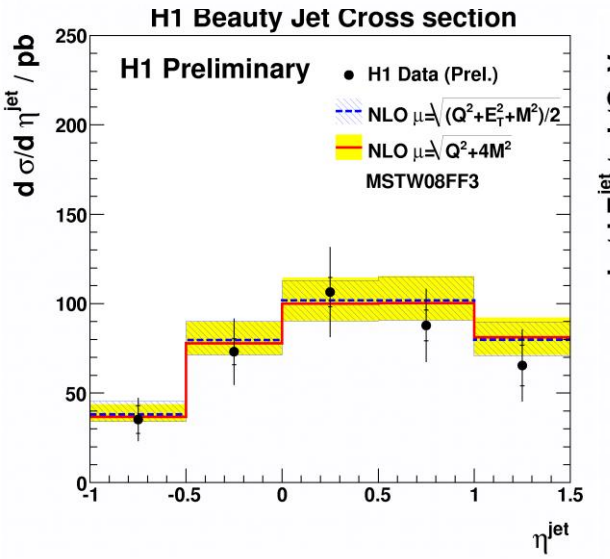
$6<Q^2<1000\ GeV^2$
$0.07<y<0.625$
$E_T^{jet}>6\ GeV$
$-1<\eta^{jet}<1.5$

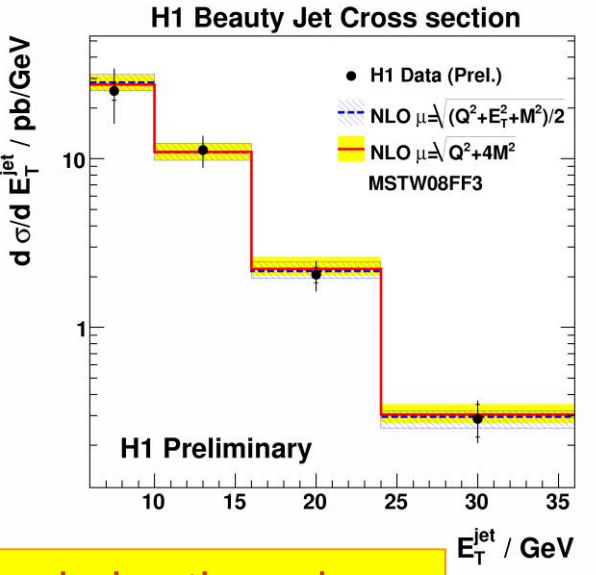
Requiring a high E_T jet introduces another hard scale











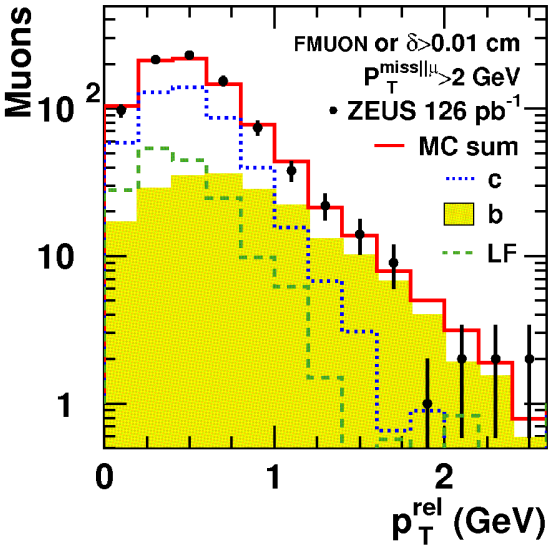
Beauty less sensitive to scale choice than charm

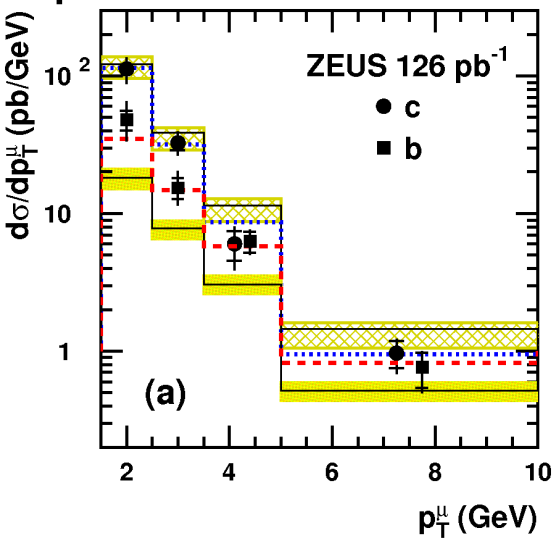
charm & beauty →μ in DIS

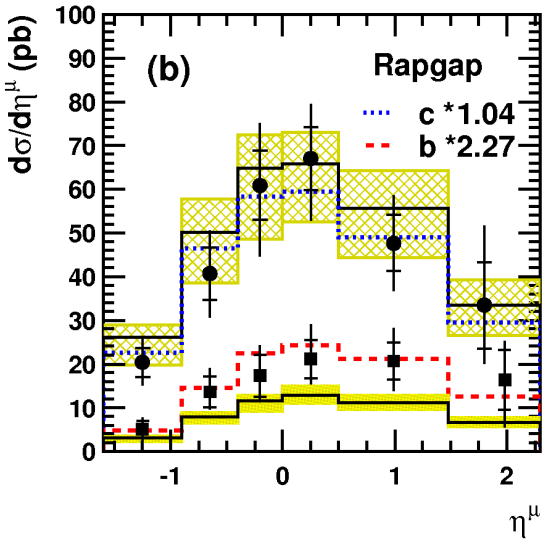
ZEUS

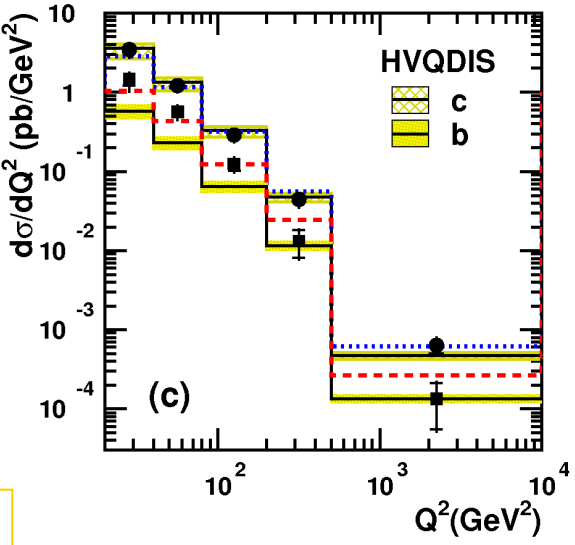
data sample: 126 pb^{-1} (2005)

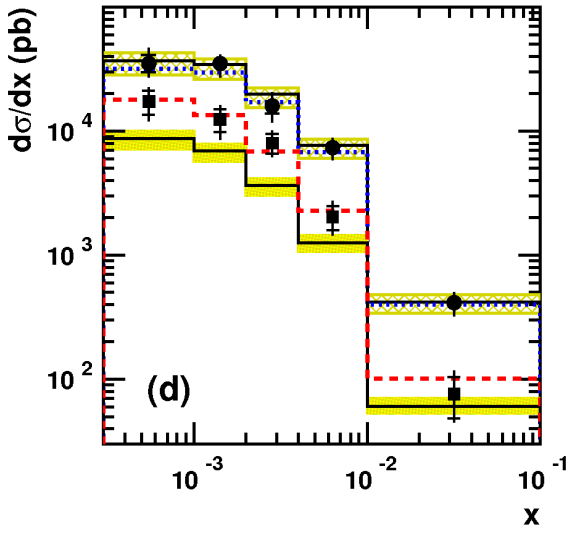
Q^2>20 GeV^2
0.01 <y<0.7
-1.6<η_μ <2.3
p_T^μ>1.5 GeV
p_T^{jet}>2.5 GeV











3-dimensional fit of p_T^{rel}, missing pt and impact parameter δ of muon using MC templates

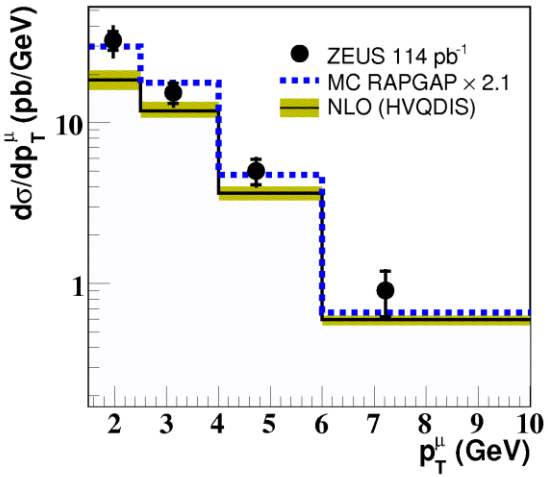
Charm: agreement with HVQDIS and RAPGAP
Beauty: predictions below the data at low Q^2

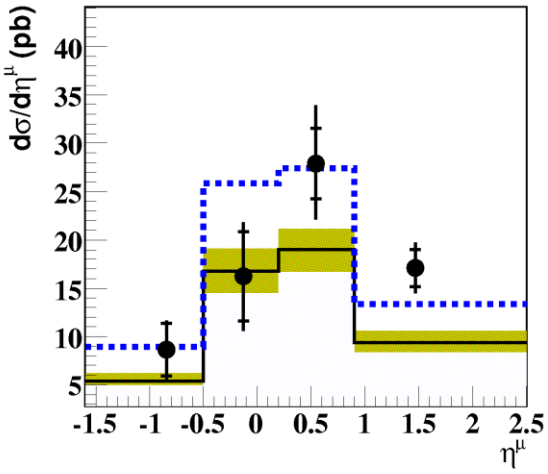
Beauty →μ in DIS (HERA I)

data sample: 114 pb^{-1} (1996-2000)

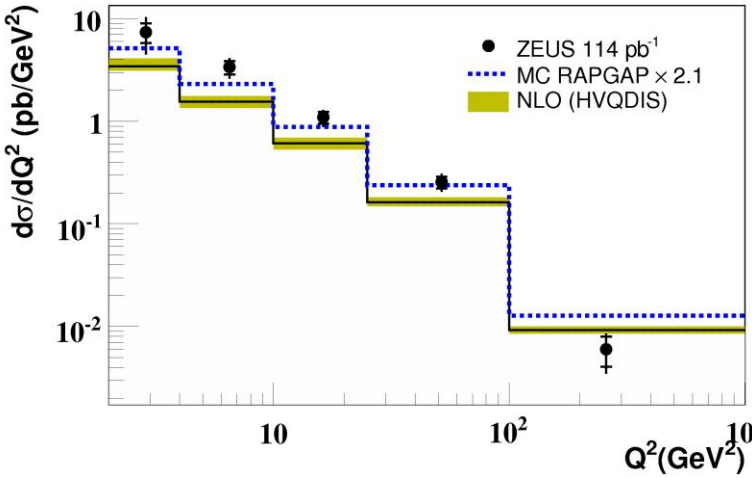
Q^2>2 GeV^2
0.05 <y<0.7
η^{μ} >-1.6
p_T^{μ}>1.5 GeV
$E_T^{jet,lab}$>5 GeV
-2<η^{jet}<2.5

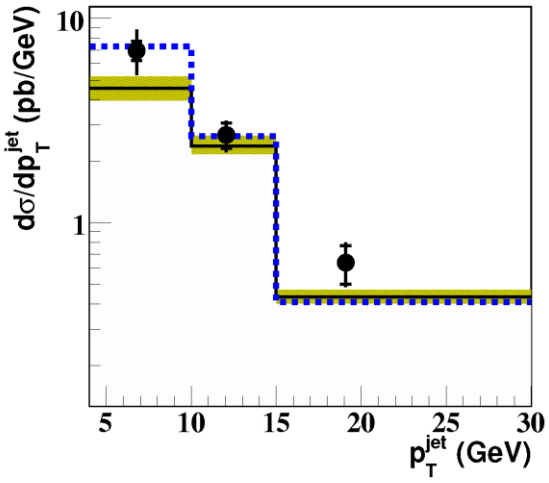
ZEUS

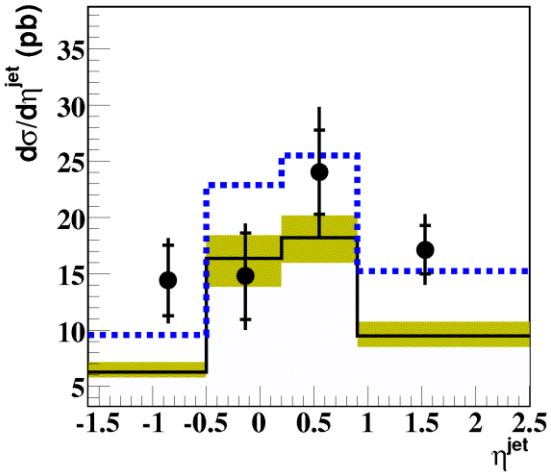




ZEUS





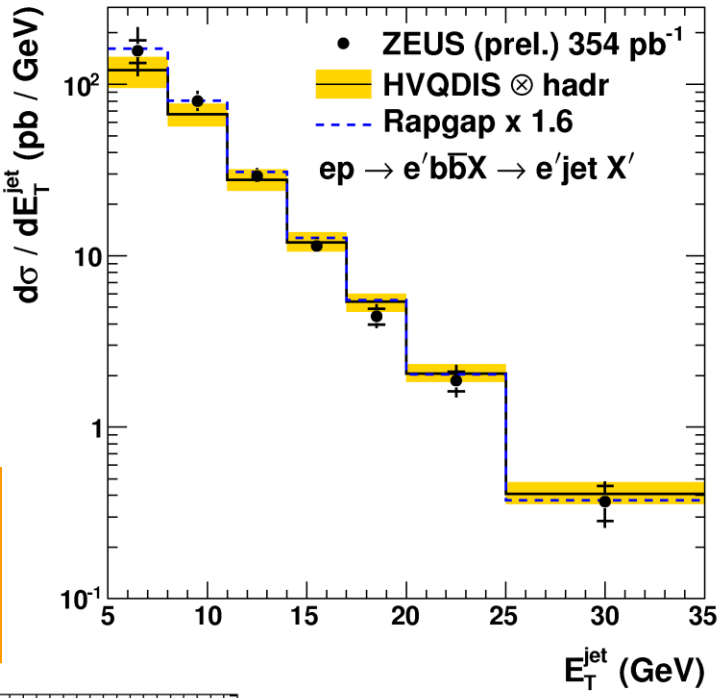


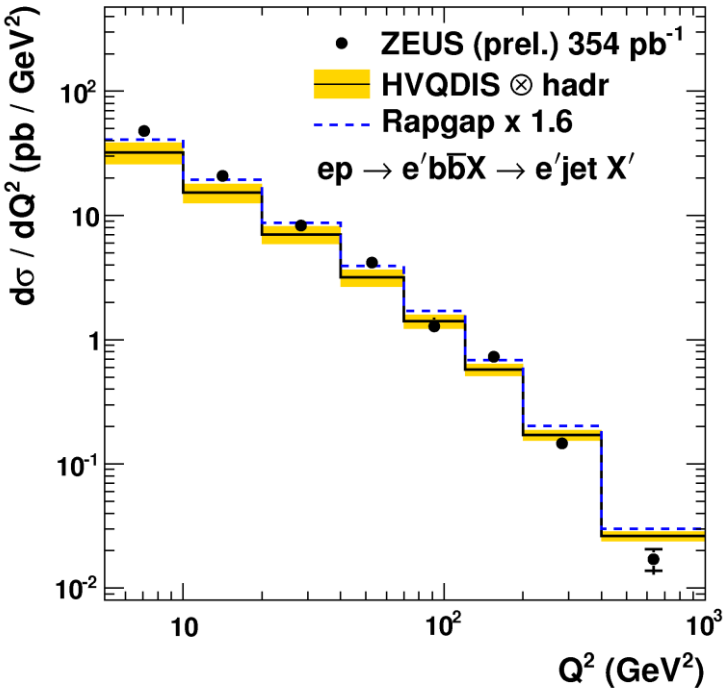
Acceptable description by HVQDIS
Similar differences as in previous analysis

Beauty using secondary vertices

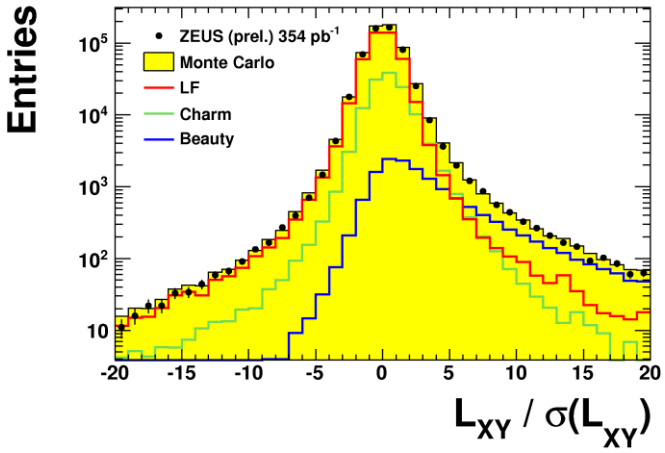
data sample: 354 pb^{-1} (2004 -07)

$5<Q^2<1000$ GeV^2
$0.02<y<0.7$
$E_T^{jet,lab}>5$ GeV
$-1.6<\eta^{jet}<2.2$





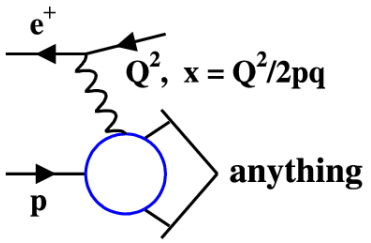
Measurement using secondary vertices



Good agreement with HVQDIS NLO QCD

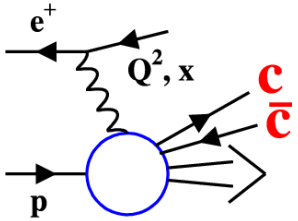
F_2^{bb} and F_2^{cc} contributions to the proton structure function F_2

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}x\mathrm{d}Q^2} = \frac{2\pi\alpha^2}{xQ^4}[(1+(1-y)^2)F_2 - y^2F_L]$$



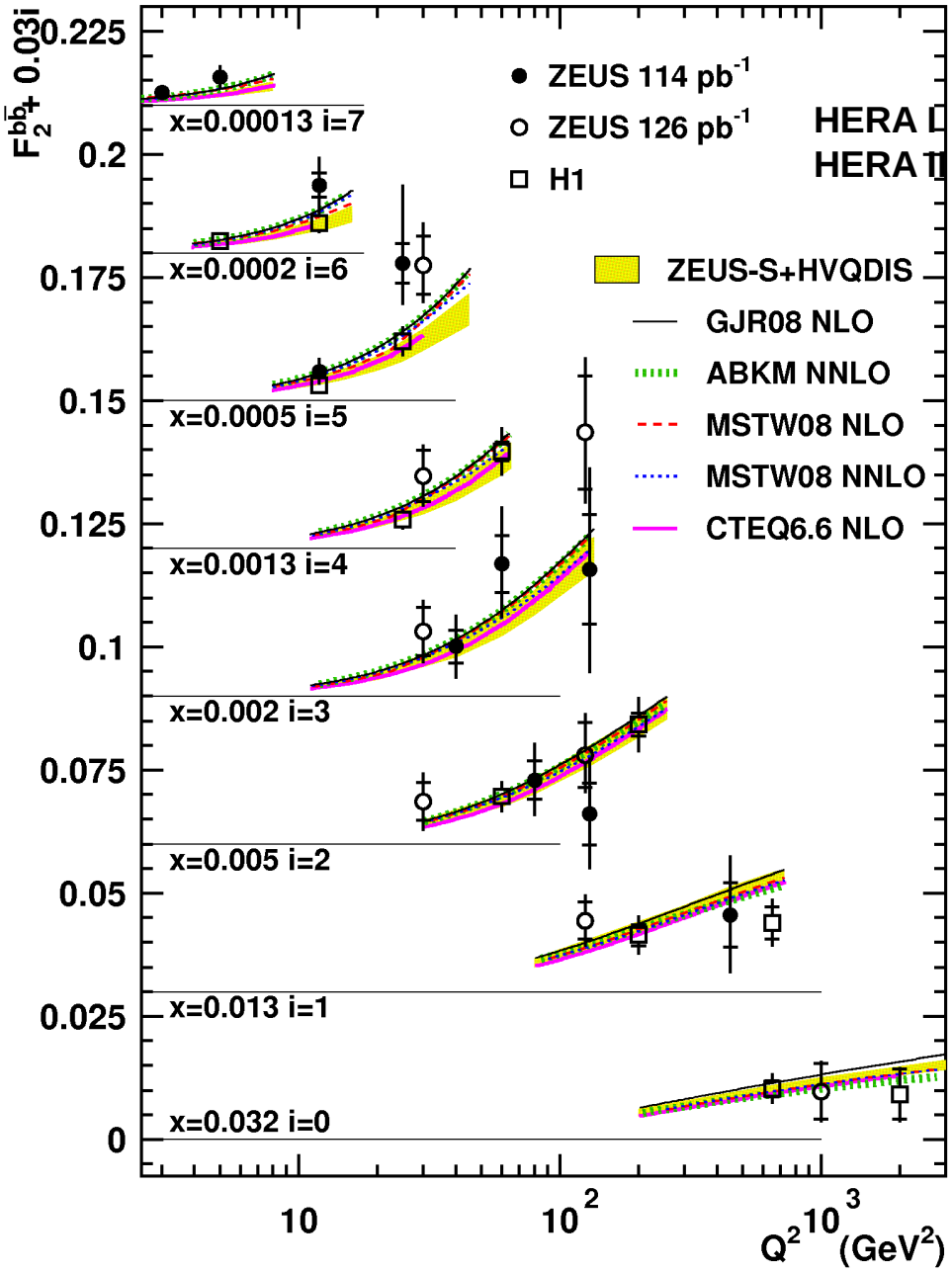
$$\frac{d^2\sigma^{ep}}{dQ^2dx} \propto F_2(x,Q^2)$$

$$\frac{\mathrm{d}^2\sigma^{c\bar{c}}}{\mathrm{d}x\mathrm{d}Q^2} = \frac{2\pi\alpha^2}{xQ^4}[(1+(1-y)^2)F_2^{c\bar{c}} - y^2F_L^{c\bar{c}}]$$



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

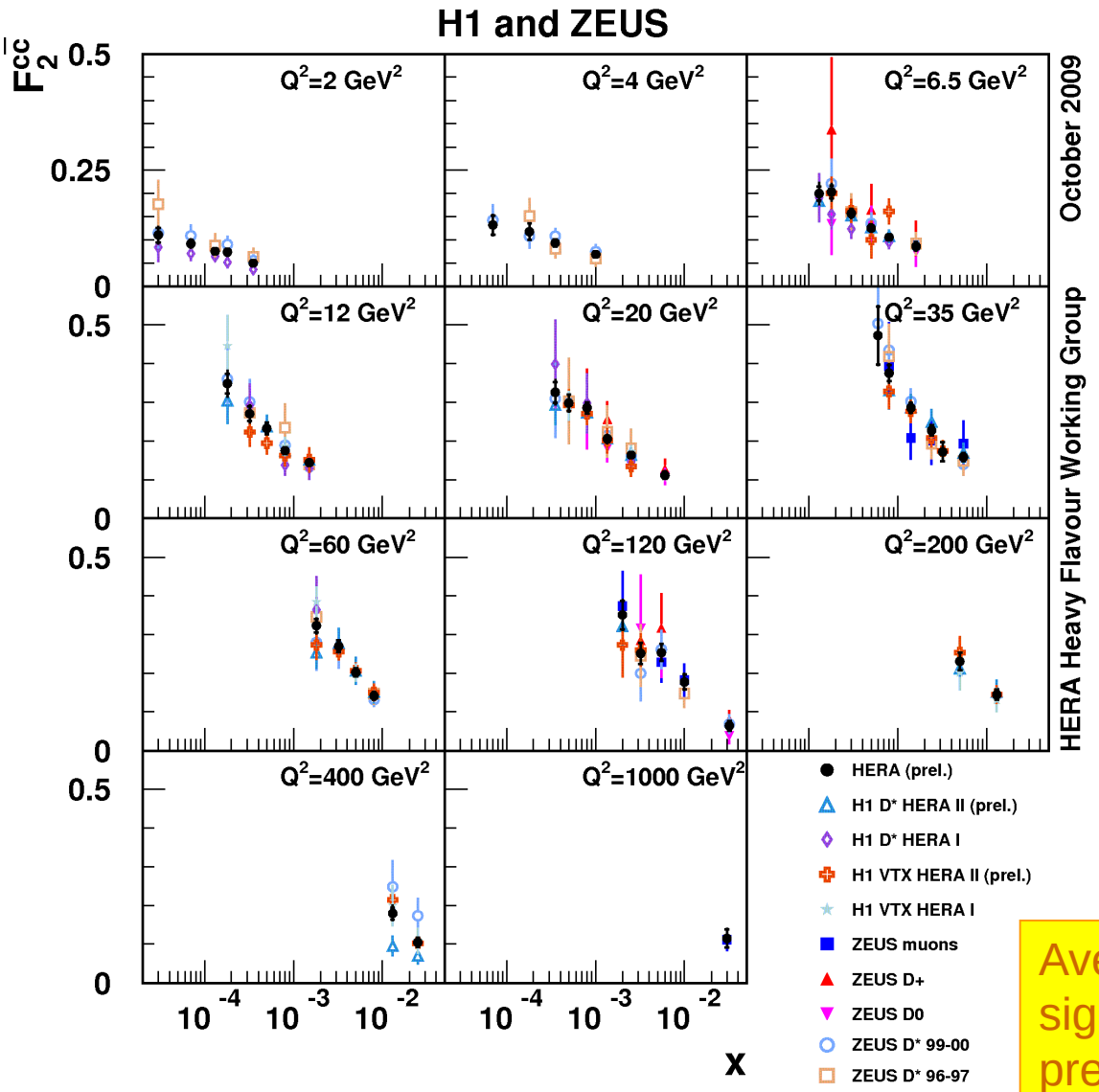
F_2^{bb} MEASUREMENT

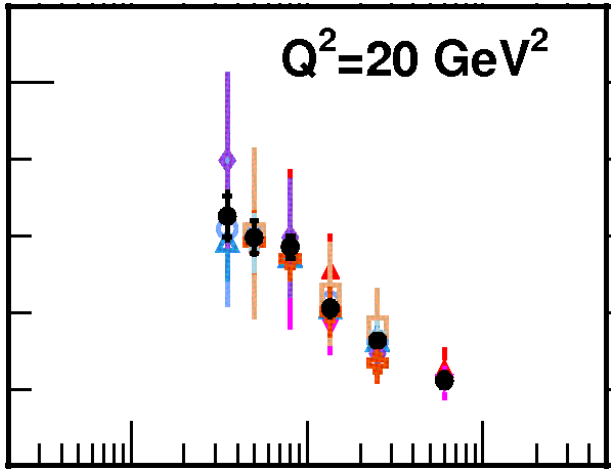


Results of different analyses agree
Predictions agree with data

F_2^{cc} combined measurement

H1prelim-09-171
ZEUS-prel-09-015

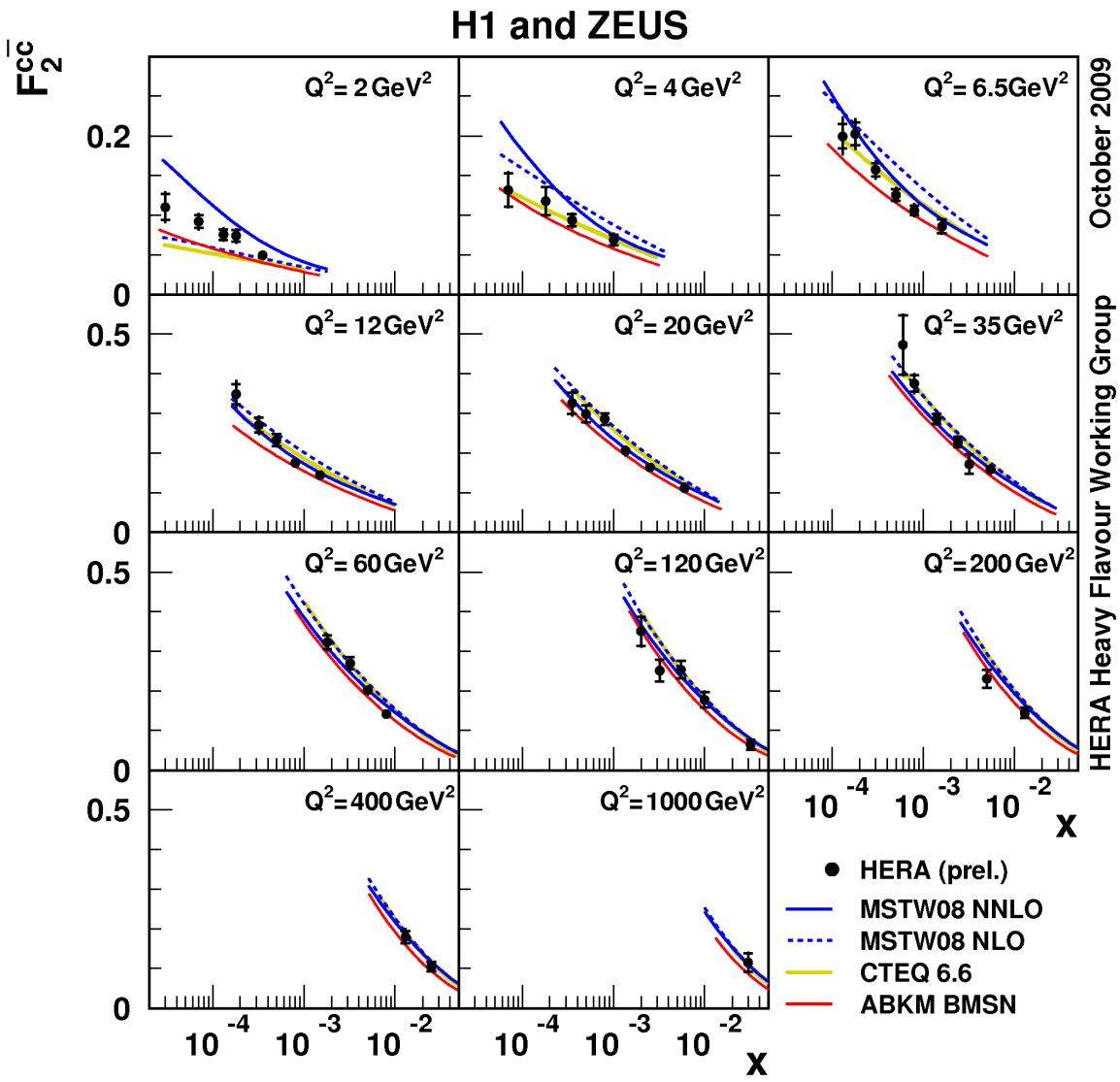




Averaging 9 different analyses: significantly smaller error, precision 5÷10%

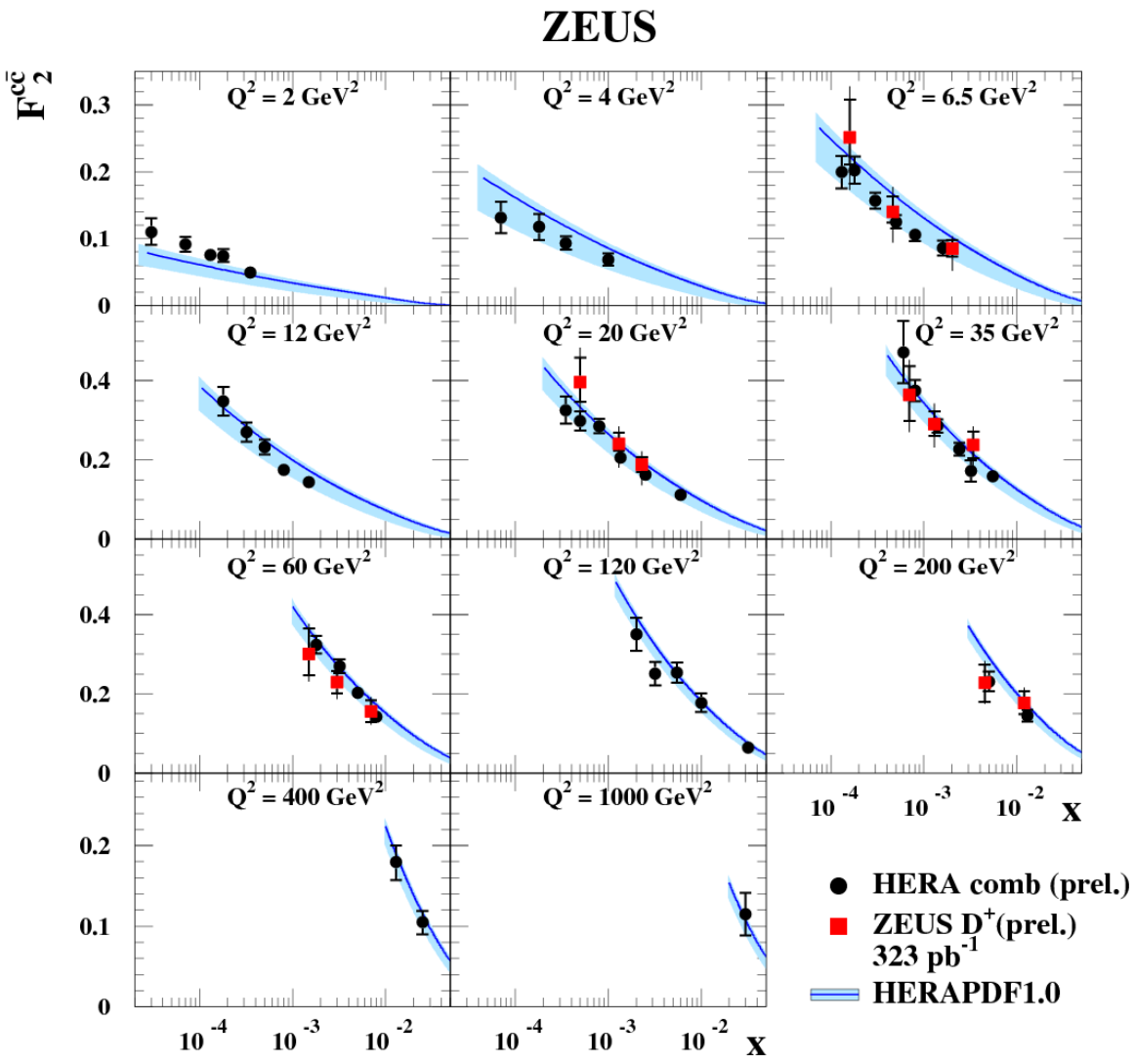
F_2^{cc} combined measurement

H1prelim-09-171
ZEUS-prel-09-015



Comparison with GM-VFNS: precision of the data is smaller than variation of different predictions

F_2^{cc} combined measurement

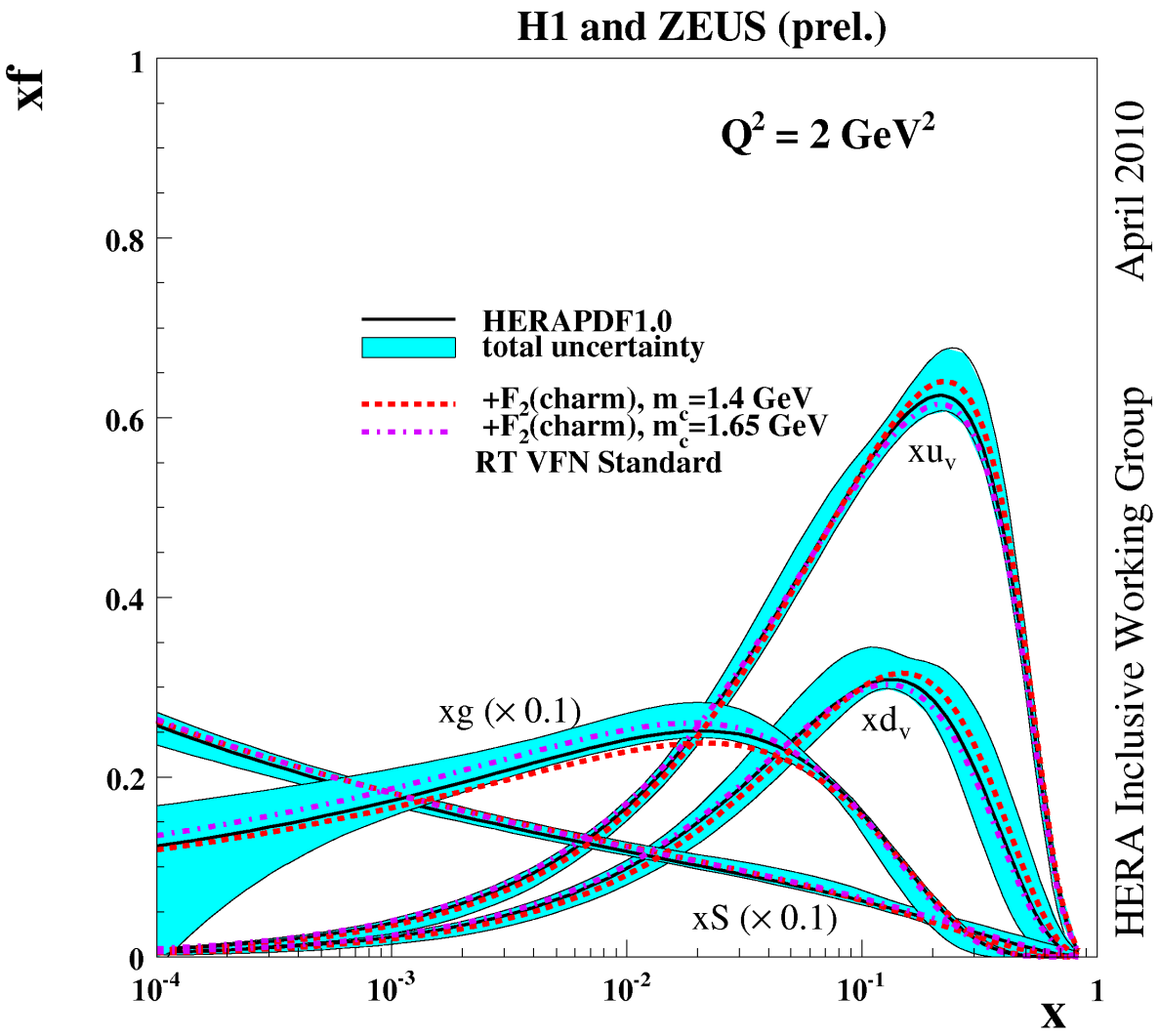


Agreement with independent measurement of HERAPDF1.0

ZEUS D± (red): result of new analysis compatible with the combined result

Proton PDF fits including combined F_2^{cc}

H1prelim-10-045
ZEUS-prel-10-009



Using combined F_2^{cc} measurement makes the PDF fit more stable against different treatment of charm mass

Summary and conclusions

Some of the latest Heavy Flavour analyses from H1 and ZEUS presented

General agreement with QCD predictions

F_2^{bb} and F_2^{cc} - different measurements compatible

Charm measurement is about to be included in the global PDF fit