Heavy Flavour and Jet Production at HERA

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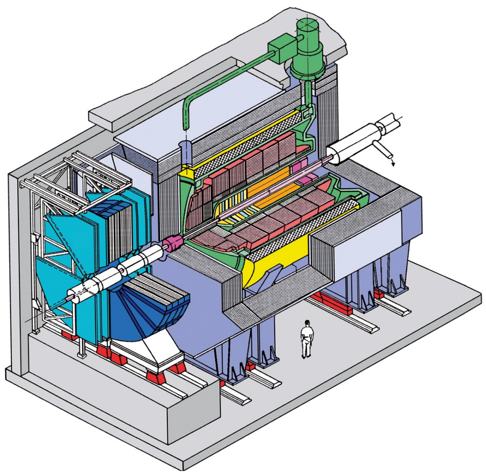
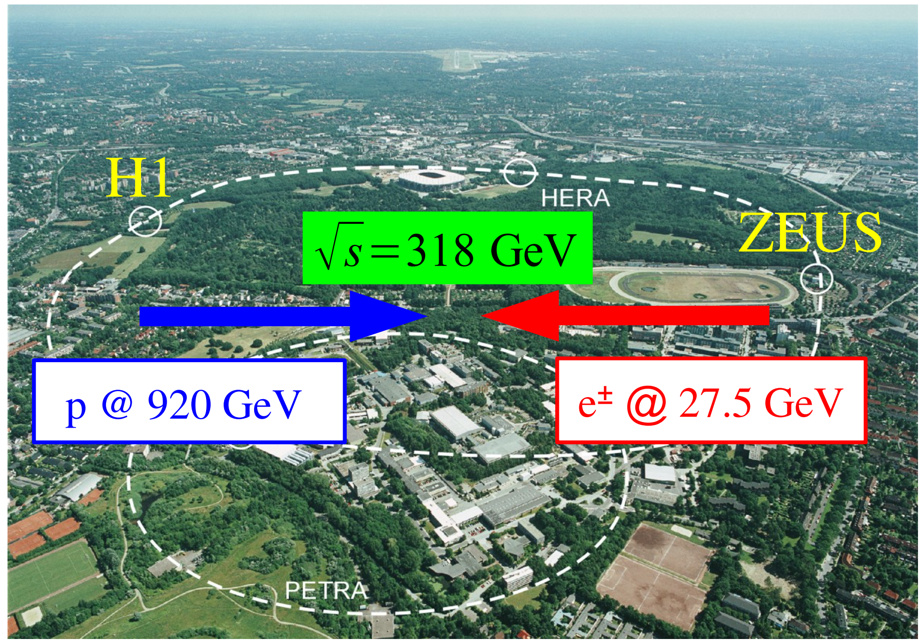
for the H1 and ZEUS Collaborations

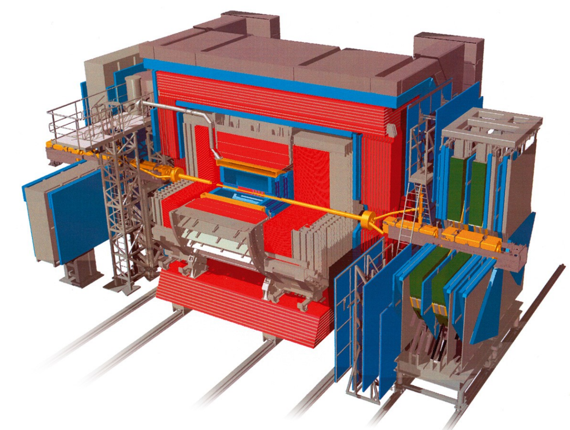
XL International Symposium on Multiparticle Dynamics (ISMD 2010)

21th - 25th September 2010

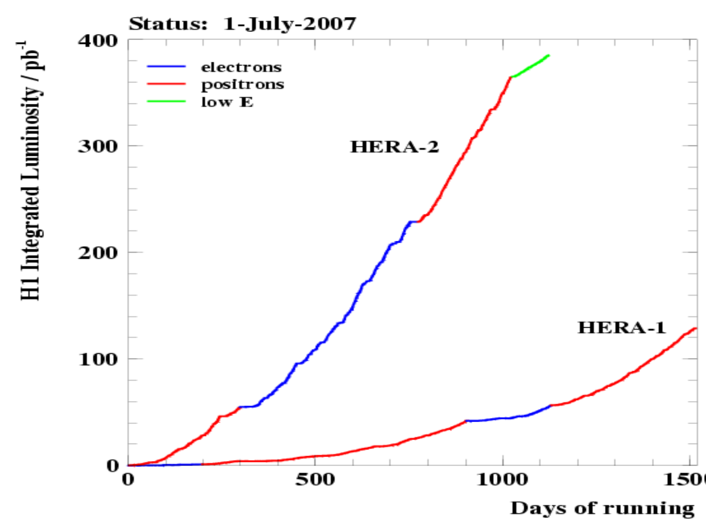
HERA







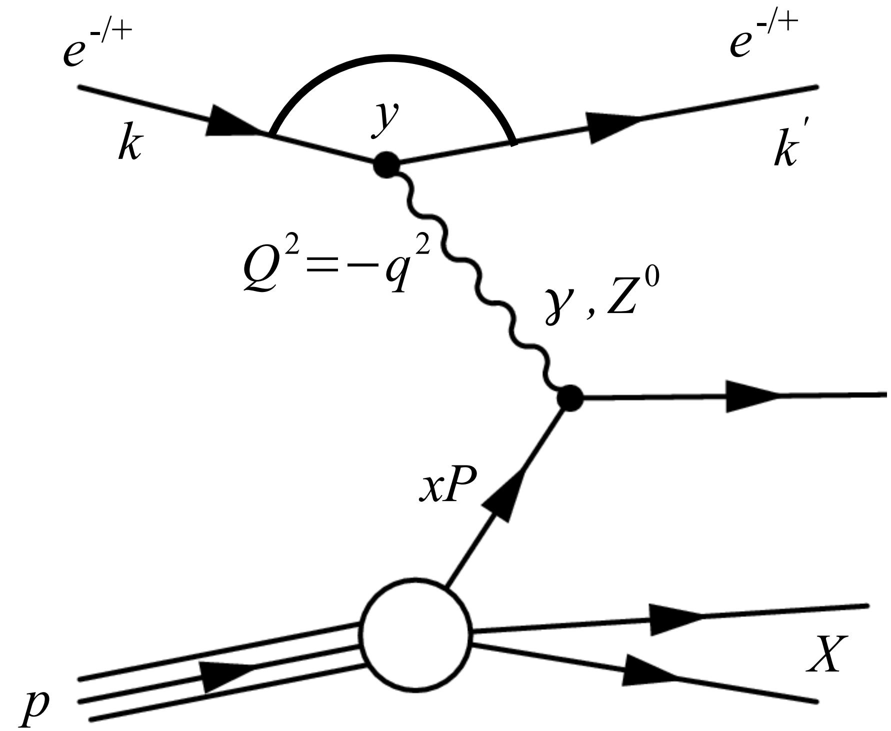
- HERAI: 1992-2000 and HERAII: 2003-2007
- ~ 0.5 fb^{-1} per experiment



Kinematics at HERA

Kinematic Quantities:

- Center of mass Energy: $s=(P+k)^2$
- Photon virtuality: $Q^2=-q^2=(k-k')^2$
- Inelasticity: $y=\frac{Pq}{Pk}$
- Bjorken Variable: $x=\frac{Q^2}{2Pq}$



Kinematic Regimes:

- $Q^2 \approx 0\, GeV^2$: Photoproduction (PHP)
- $Q^2 \geq 1\, GeV^2$: Deep inelastic scattering (DIS)

Jet Production at HERA

QCD factorisation:

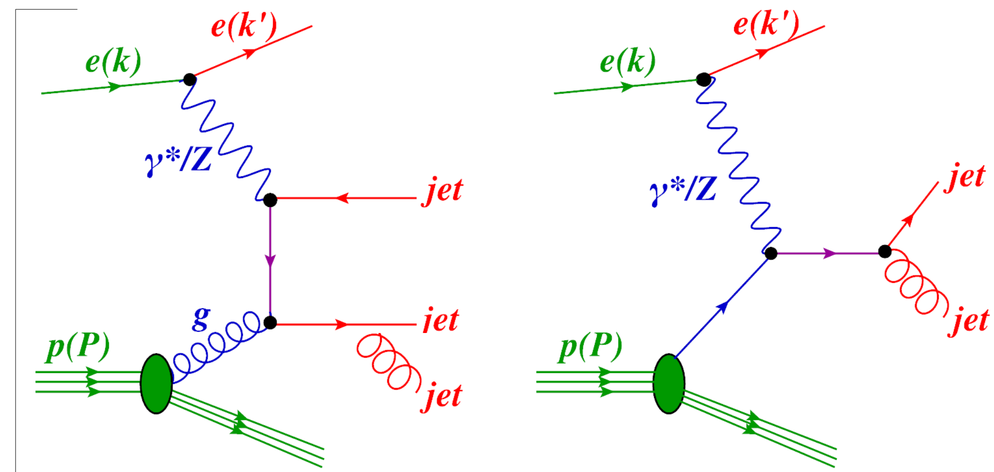
$$\sigma_{jet} \propto f_{p/\gamma} \otimes \hat{\sigma} \otimes (1+\delta_{had})$$

- $f_{p/\gamma}$: parton distribution functions (PDFs) for proton (and photon)
- $\hat{\sigma}$: hard scattering matrix element
- δ_{had} : hadronisation correction

Measurement of jet production at HERA provides powerful tool for:

- ➔ Constraints on PDFs
- ➔ Testing ground of perturbative QCD
- ➔ Precision measurement of running strong coupling constant

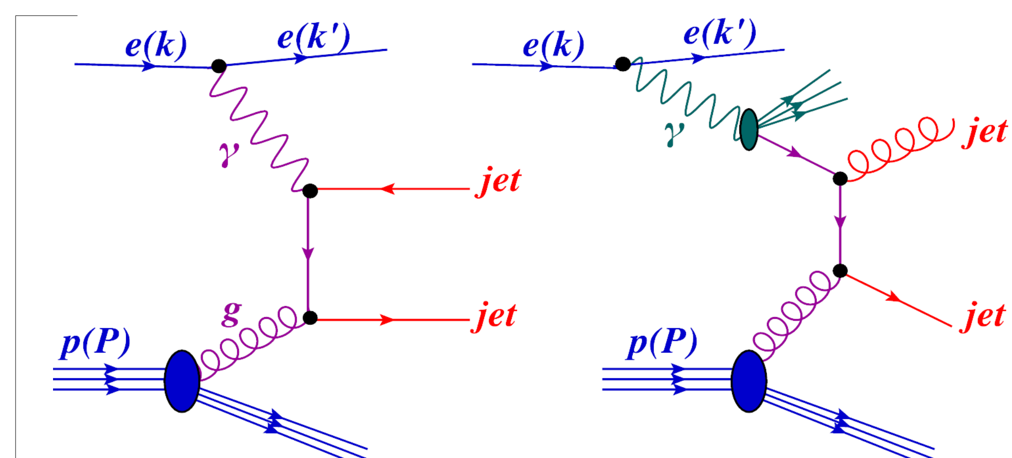
Jet Production in DIS



Boson-gluon fusion (BGF)

QCD Compton

Jet Production in PHP

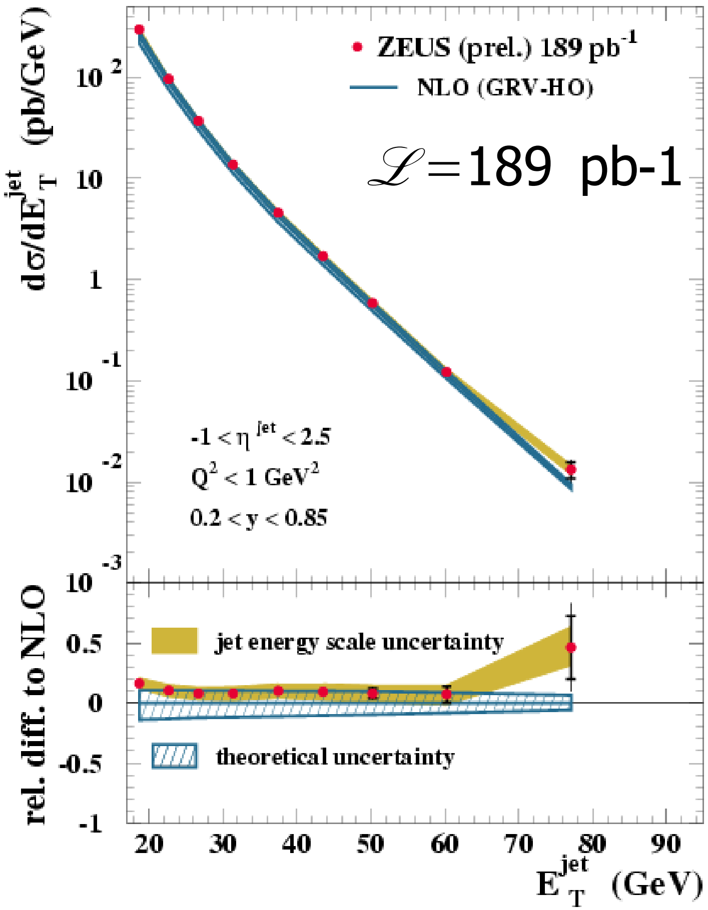


Direct process (BGF)

Resolved process

Inclusive Jet Cross Sections

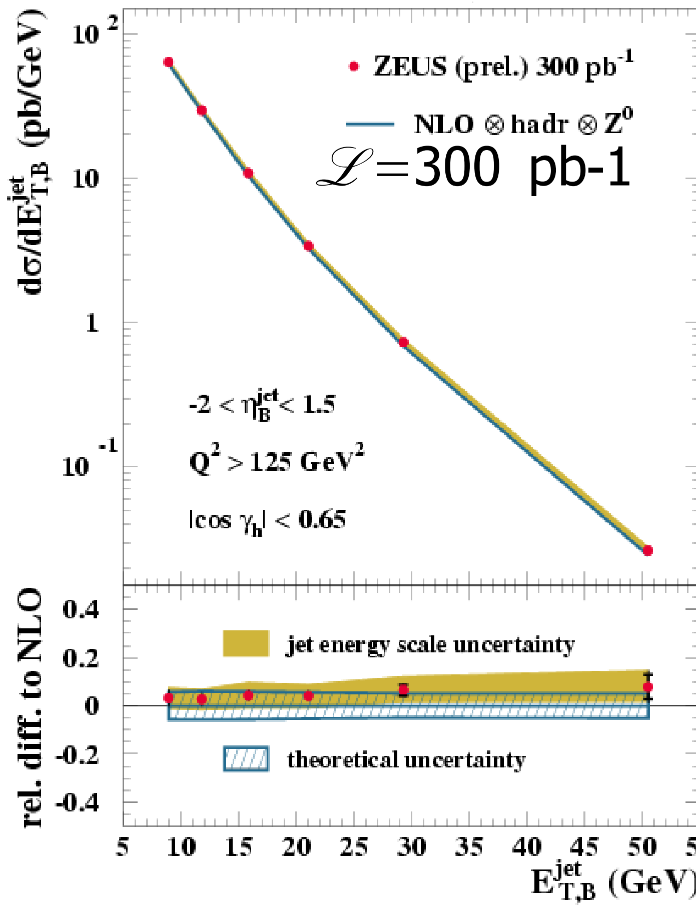
Photoproduction



Neutral current DIS

ZEUS-prel-10-002

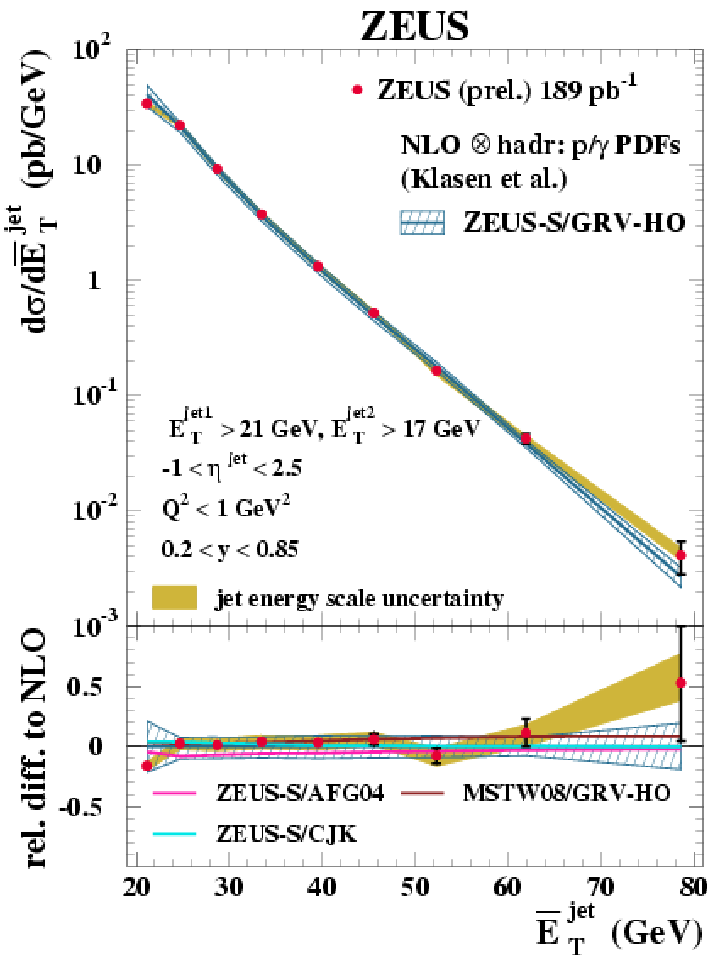
ZEUS-prel-10-003

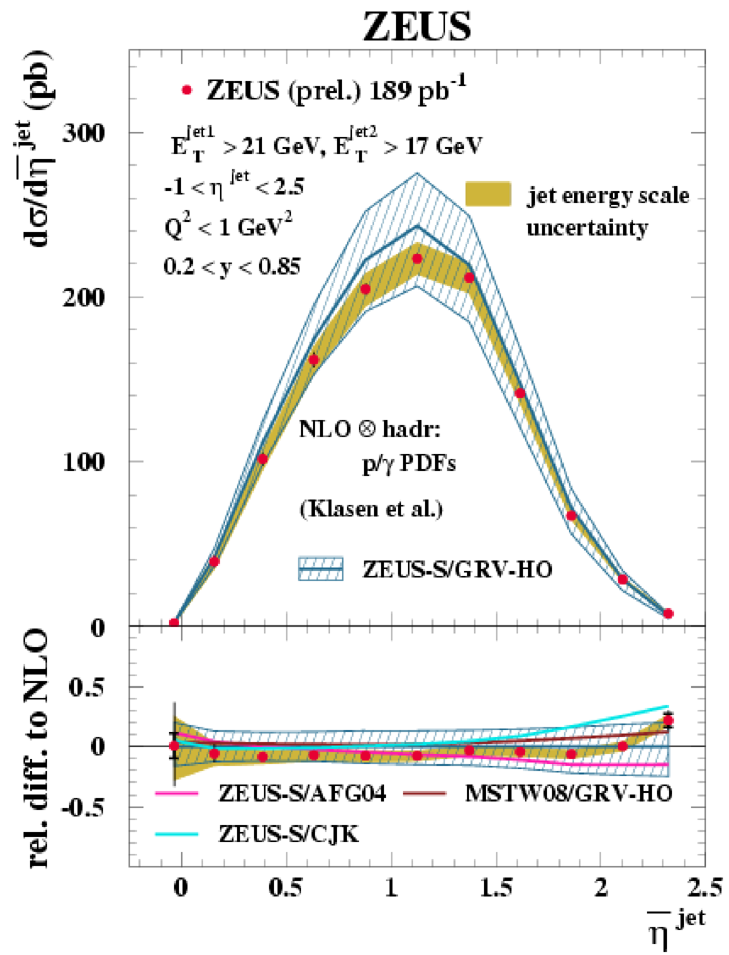


- Cross sections well described by NLO predictions
- Measurements provide direct sensitivity to α_s
- Very precise data → stringent test of (p)QCD from $Q^2 \sim 0 - 20000$ GeV^2

Dijets in Photoproduction

$\mathscr{L}$=189 pb-1 ZEUS-prel-10-014





- Good description of data by NLO QCD in the whole measured range
- Sensitivity to photon (high η^{jet}) PDFs

Multijets at low Q^2

$\mathscr{L}$=44 pb^{-1} H1: Eur Phys J. C67 (2010) 1

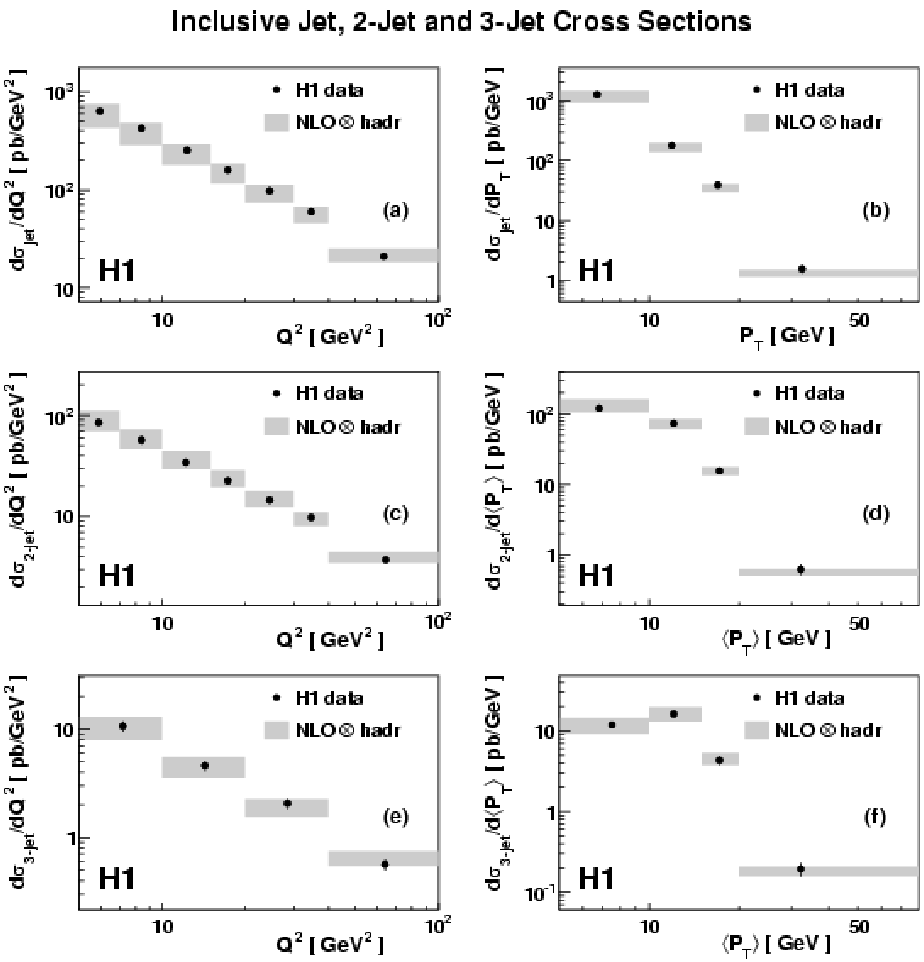
- Multijet cross sections as a function of Q^2 and p_t^{jet}

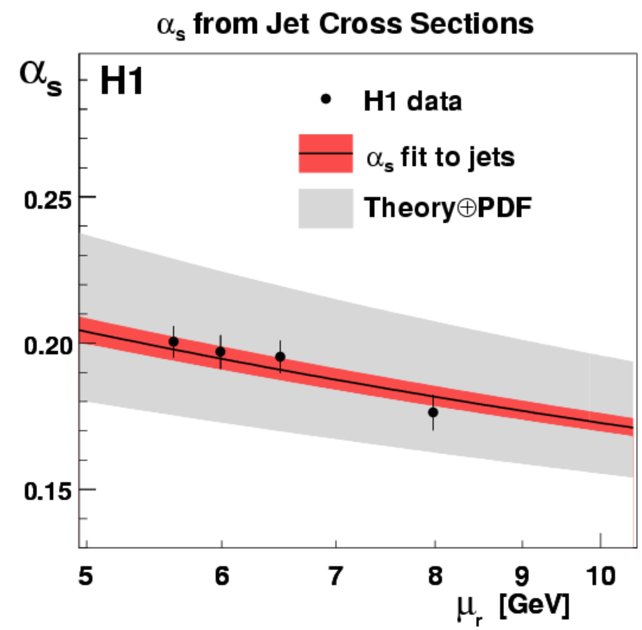
$5 < Q^2 < 100$ GeV^2, $0.2 < y < 0.7$
$p_t^{jet} > 5$ GeV, $-1 < \eta_{lab} < 2.5$

incl. jet

2 jet

3 jet





- Extract α_s from a simult. Fit of inclusive, dijet and trijet measurements

➔ Data much more precise than theory

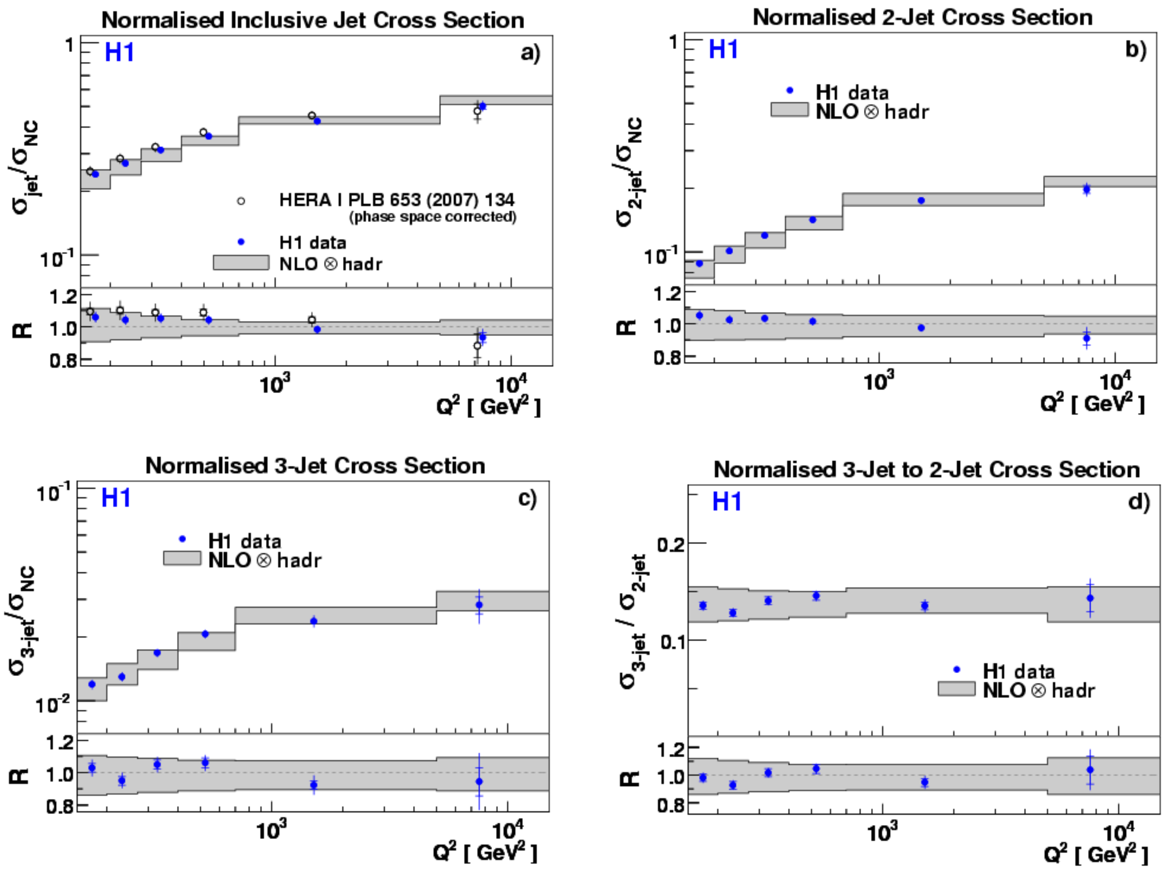
➔ Good description of data by NLO predictions

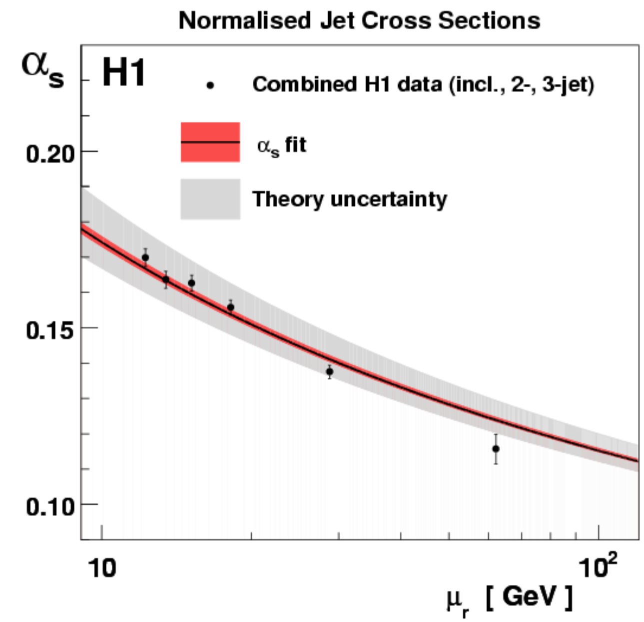
Multijets at high Q^2

$\mathscr{L}=395\ pb^{-1}$ H1: Eur Phys J. C65 (2010) 363

- Cross sections normalised to DIS cross section

$150 < Q^2 < 15000\ GeV^2$, $0.2 < y < 0.7$
$p_t^{jet} > 7(5)\ GeV$, $-0.8 < \eta_{lab} < 2$





→ Simultanous fit of all norm. jet cross sections

→ Smaller theoretical uncertainties due to higher scale

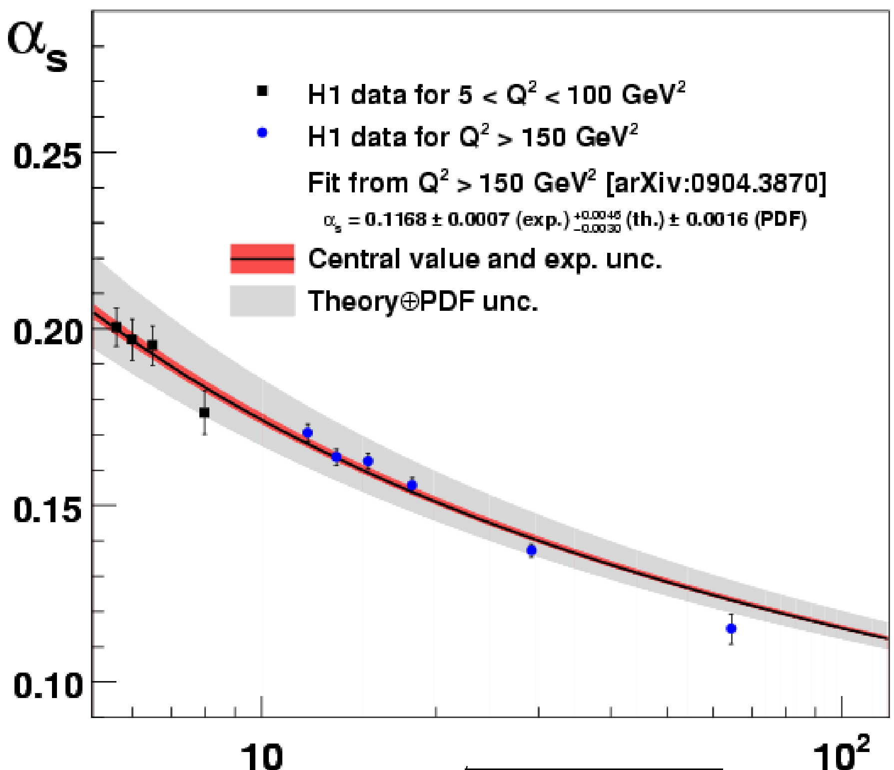
→ Good description of data by NLO predictions

Running α_s from H1 and ZEUS

H1: Eur Phys J. C67 (2010) 1

H1: Eur Phys J. C65 (2010) 363

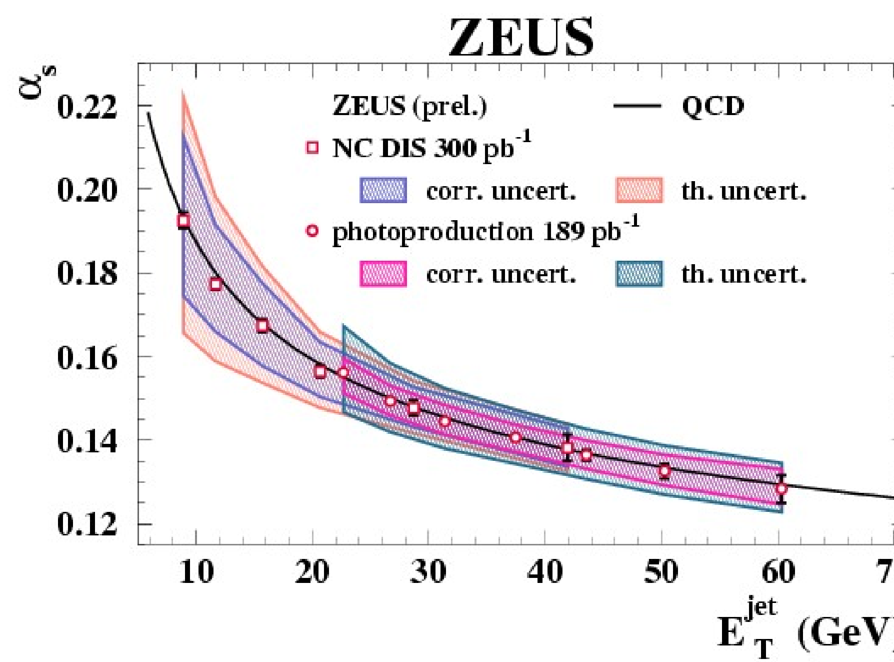
α_s from Jet Cross Sections in DIS



$\mu_r = \sqrt{(Q^2 + P_T^2)/2}\ [GeV]$

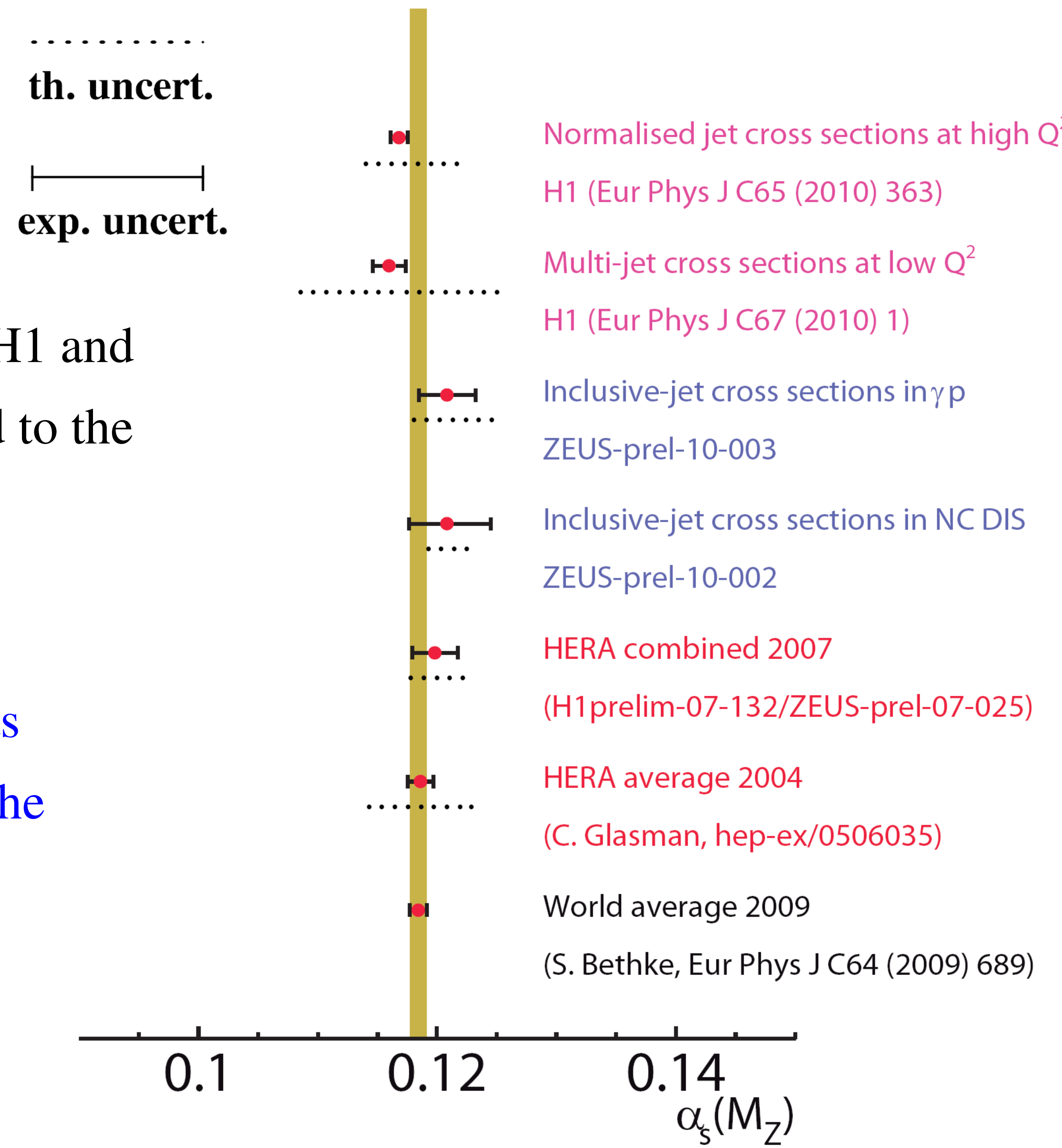
ZEUS-prel-10-002

ZEUS-prel-10-003



- Very good agreement of extraction of $\alpha_s(\mu_r)$ at low and high Q^2
- Running of α_s tested over wide range of scale

$\alpha_s(M_Z)$ from H1 and ZEUS

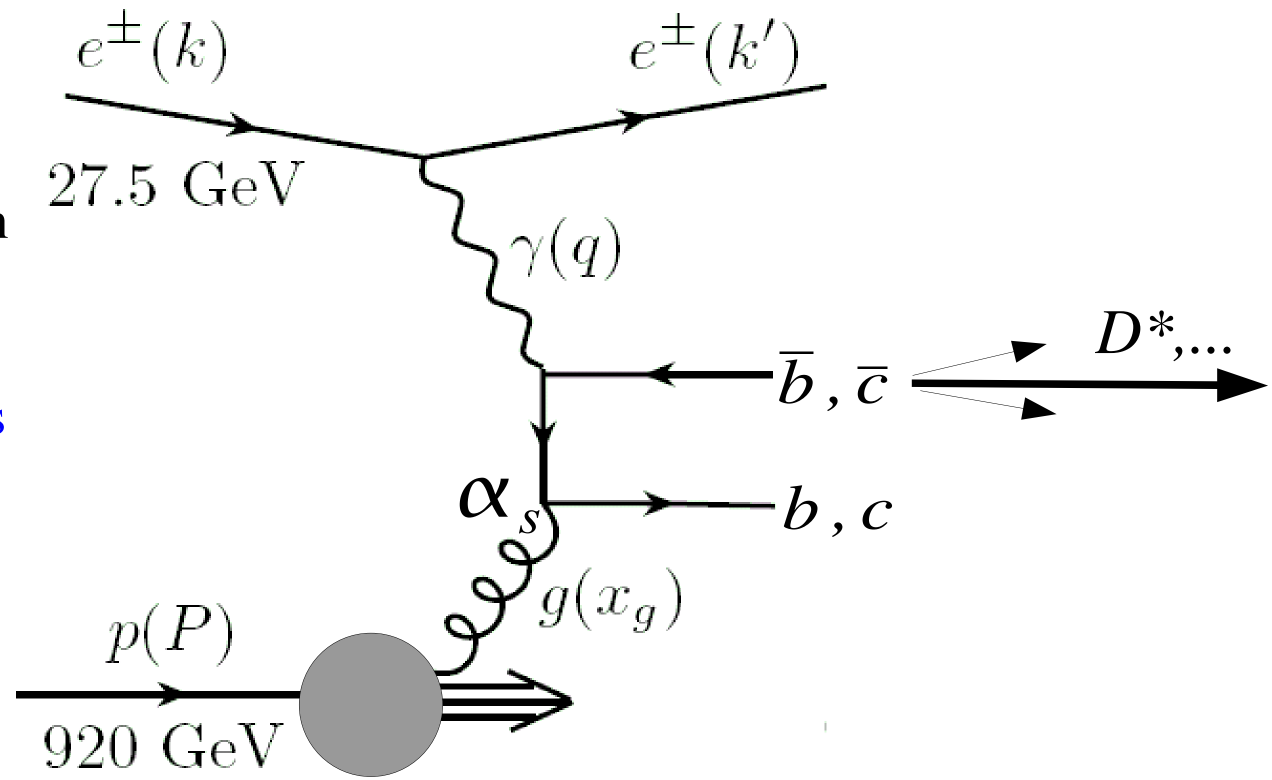


- Results of $\alpha_s(M_Z)$ from recent H1 and ZEUS measurements compared to the world average

→ Results of $\alpha_s(M_Z)$ measurements consistent with each other and the world average

Production of Heavy Quarks

- Predominantly via boson gluon fusion
- Additional scale given by mass
- High contribution to inclusive cross section



QCD factorisation:

$$\sigma_{D^*} \propto f_{p/\gamma} \otimes \hat{\sigma} \otimes D_c^{D^*}(z)$$

parton density function (non-perturbative)

parton scattering cross section (perturbative)

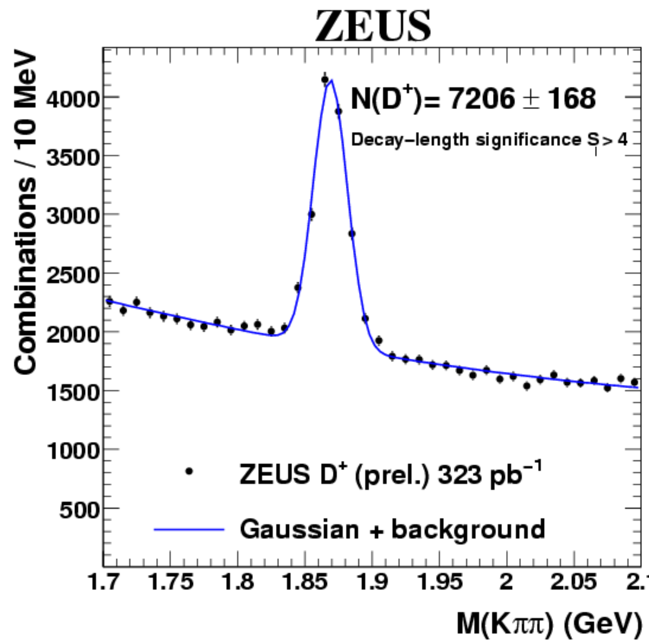
fragmentation function (non-perturbative)

Methods for Heavy Flavour Tagging

Meson identification:

- Full reconstruction from decay tracks:

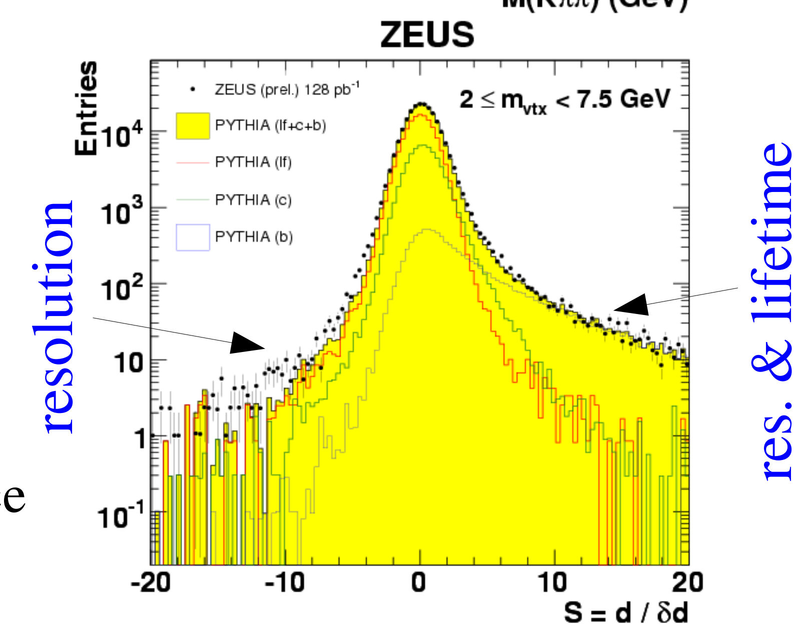
$$D^{+/-} \rightarrow K^{-/+} \pi^{+/-} \pi^{+/-}$$

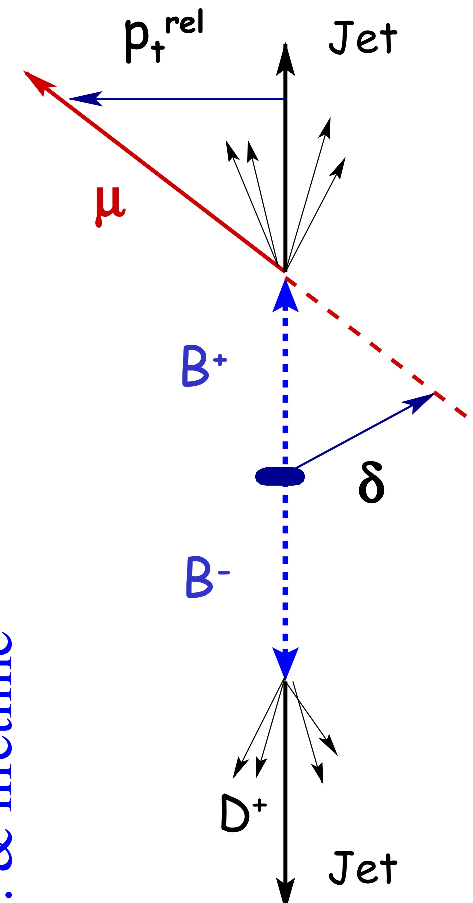


Lifetime tag:

- Reconstruct secondary vertex (with jet)
- Project decay length on jet axis
- Use decay length significance: S=d/δd

- Impact parameter significance of tracks



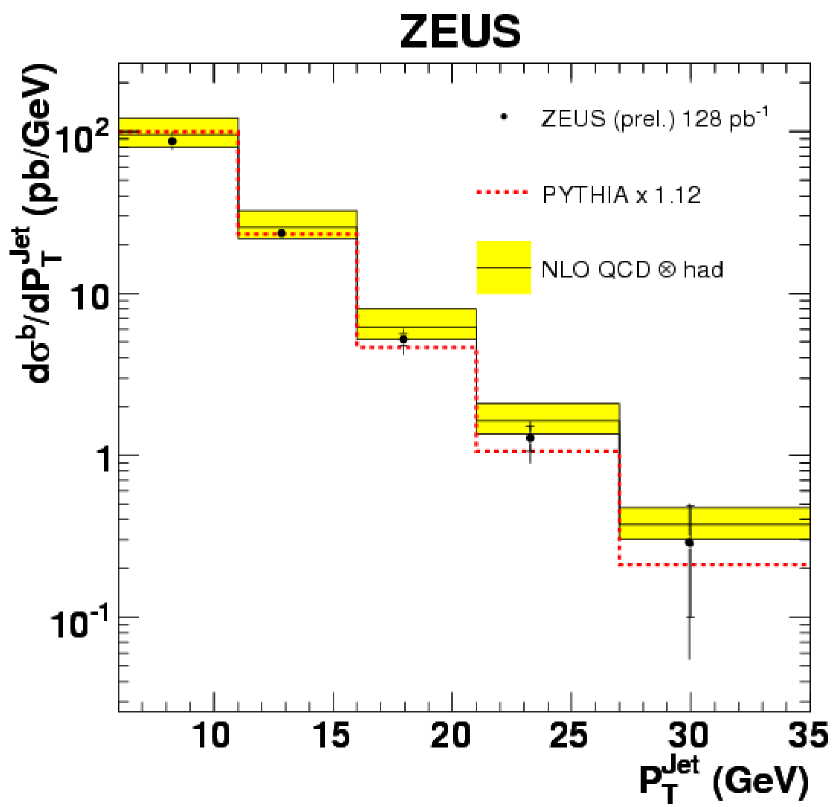


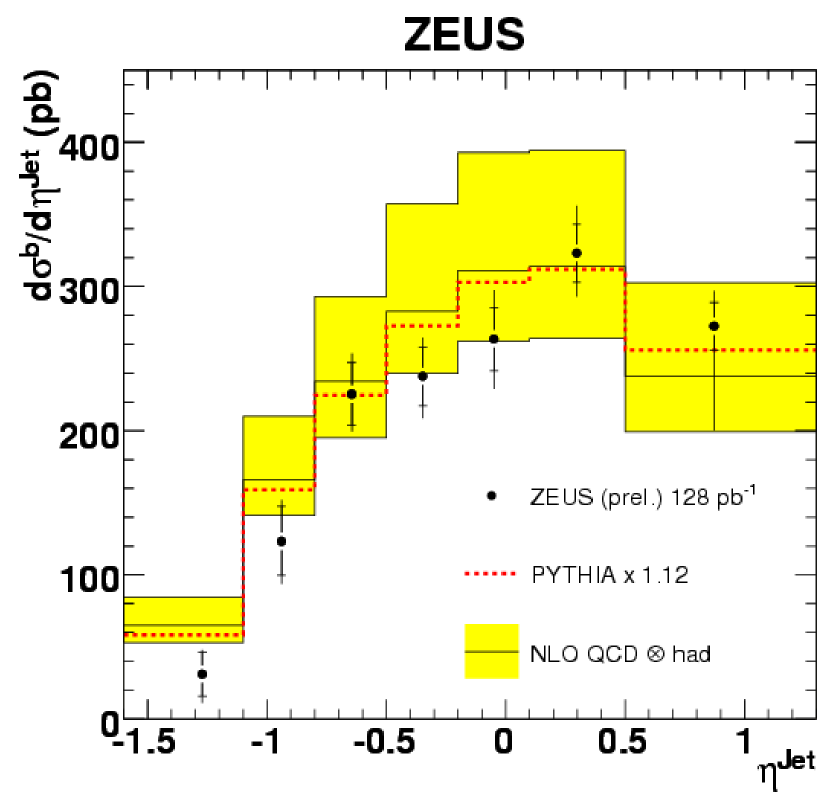
Beauty in PHP using Secondary Vertex

$\mathscr{L}$=128 pb^{-1}

$Q^2 < 1$ GeV^2, $0.2 < y < 0.8$
$p_t^{jet} > 7(6)$ GeV, $|\eta_{jet}| < 2.5$

ZEUS-prel-09-005





- Cross sections in P_t^{jet} and η_{jet} in good agreement with LO MC (Pythia) and NLO QCD calculation (FMNR)
- Theoretical uncertainties larger than experimental ones

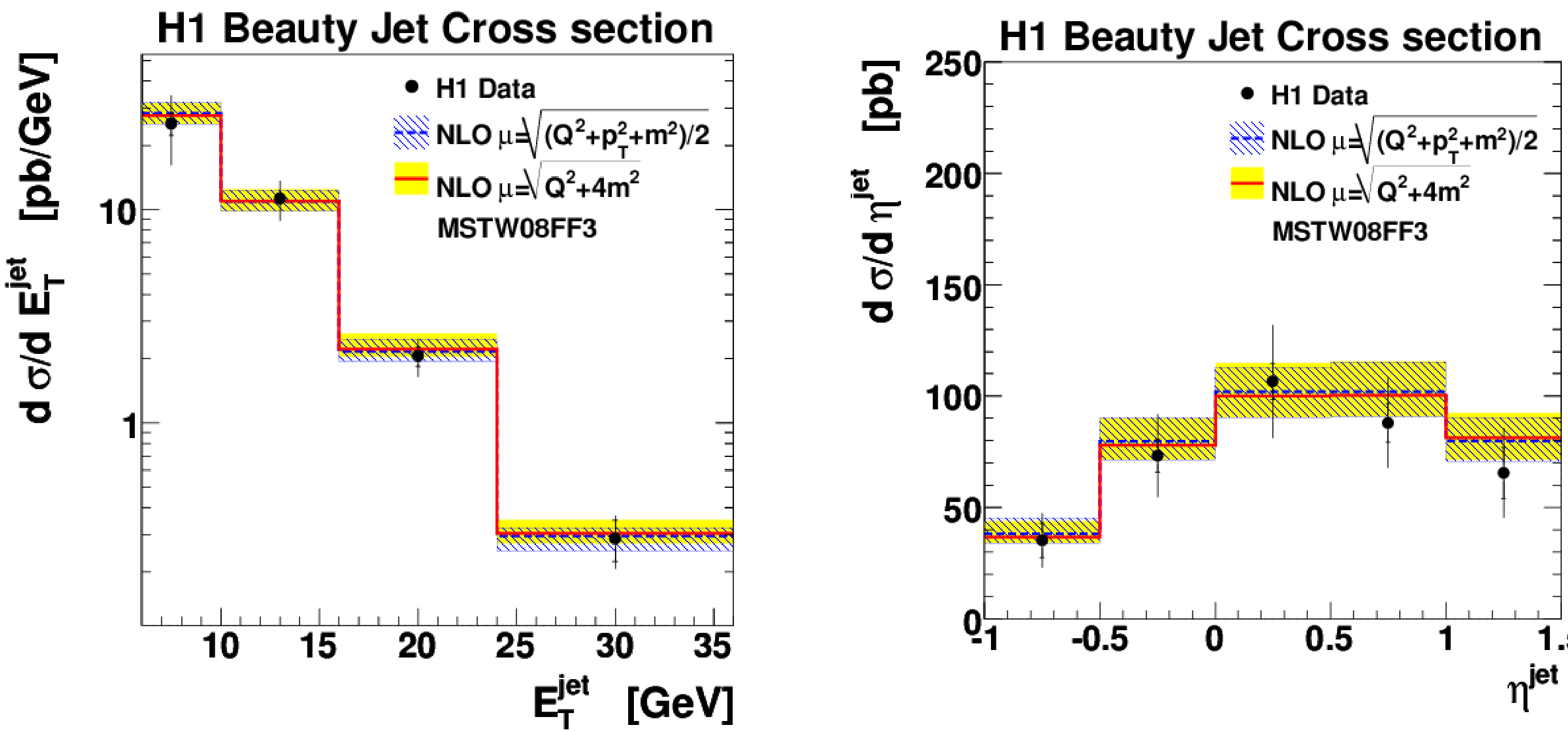
Beauty Jets in DIS

$\mathscr{L}$=189 pb^{-1}

$Q^2 > 6$ GeV^2, $0.07 < y < 0.6$
$E_t^{jet} > 6$ GeV, $-1 < \eta_{jet} < 1.5$

H1: DESY-10-083

- Use sensitivity to lifetime
- Compare data with NLO calculation HVQDIS



→ NLO QCD calculation describes data well for both scales

Beauty in DIS using Secondary Vertex

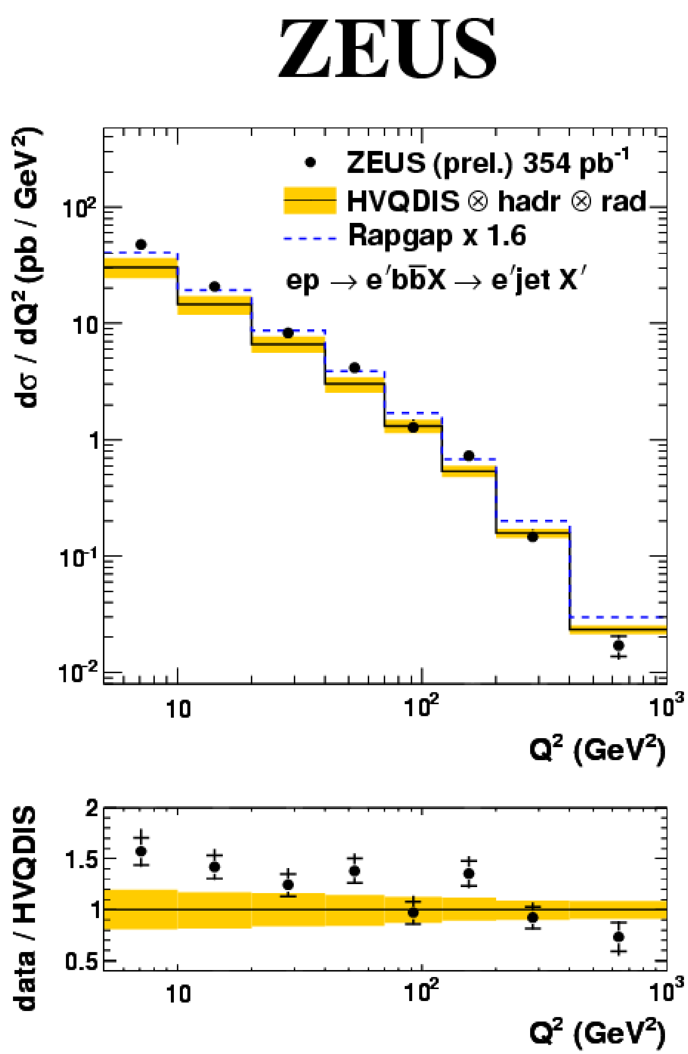
$\mathscr{L}$=354 pb^{-1}

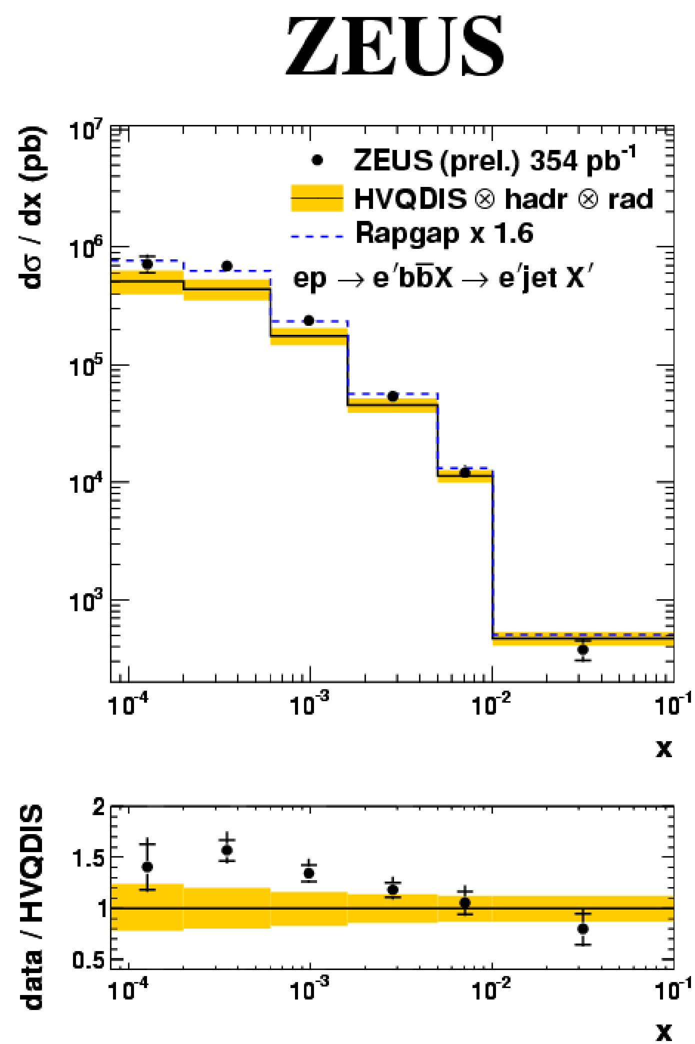
$5 < Q^2 < 1000$ GeV^2 , $0.02 < y < 0.7$
$E_t^{jet} > 5$ GeV, $-1.6 < \eta_{jet} < 2.2$

ZEUS-prel-10-004

- Compare data with LO MC RAPGAP and NLO calculation HVQDIS

→ Reasonable agreement with NLO QCD (except low Q^2 and low x)





Beauty Structure Function F_2^{bb}

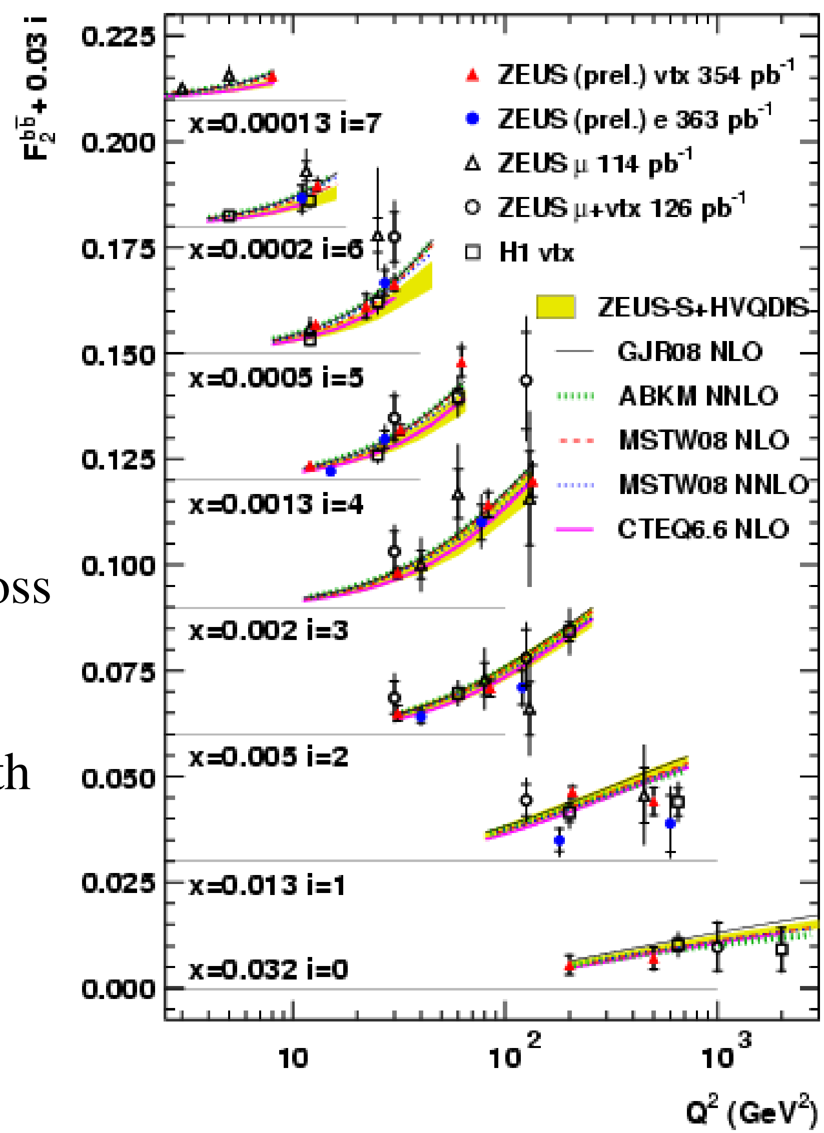
- One way to summarize beauty measurements
- Definition of F_2^{bb}:

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

Contribution of F_L^{bb} neglected !

- Estimation from measured double differential cross sections
- Measurements consistent with each other and with NLO QCD predictions
- Gain in precision with HERAII - data

F_2^{bb} at HERA



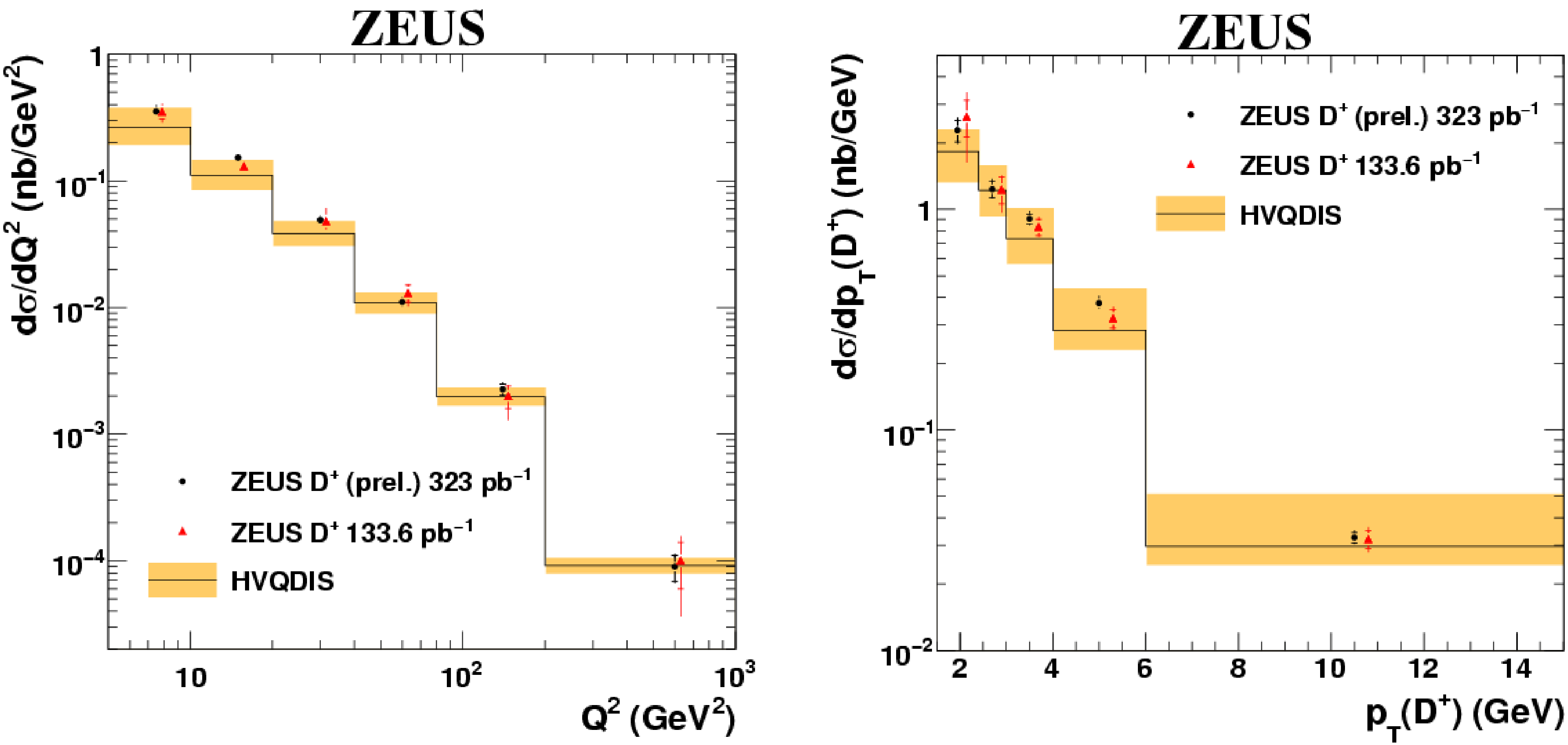
Charm ($D^{\pm}$) in DIS

$\mathscr{L}$=323 pb^{-1}

$Q^2 > 6$ GeV^2 , $0.07 < y < 0.6$
$1.5 < p_t(D^+) < 15$ GeV, $\|\eta(D^+)\| < 1.6$

ZEUS-prel-10-005

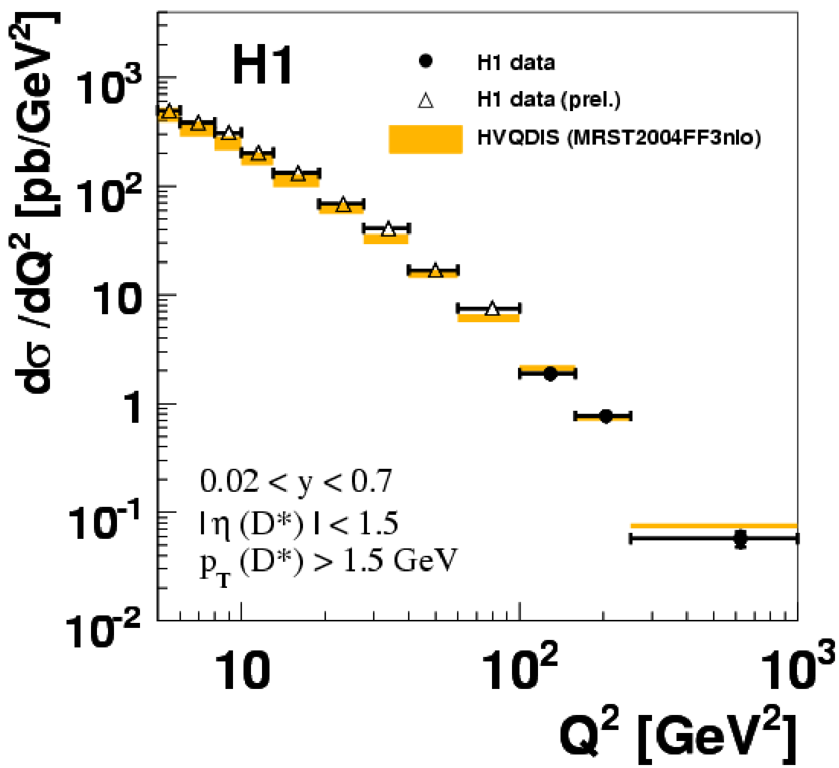
- Reconstruction: $D^+ \rightarrow K^-\pi^+\pi^+$ using lifetime information (secondary vertex)



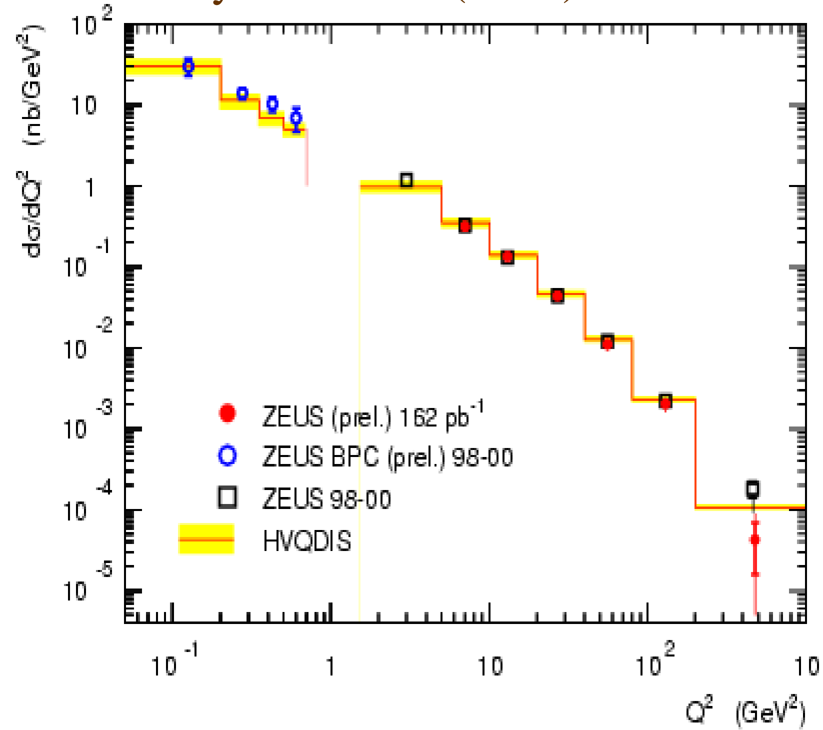
→ NLO calculation HVQDIS describes data well

D* Meson Cross Sections ($d\sigma/dQ^2$)

H1prelim-08-072
H1: Phys. Lett. B686 (2010) 91



Phys.Lett.B649 (2007) 111
ZEUS-prel-06-021
Phys.Rev.D69 (2004) 012004



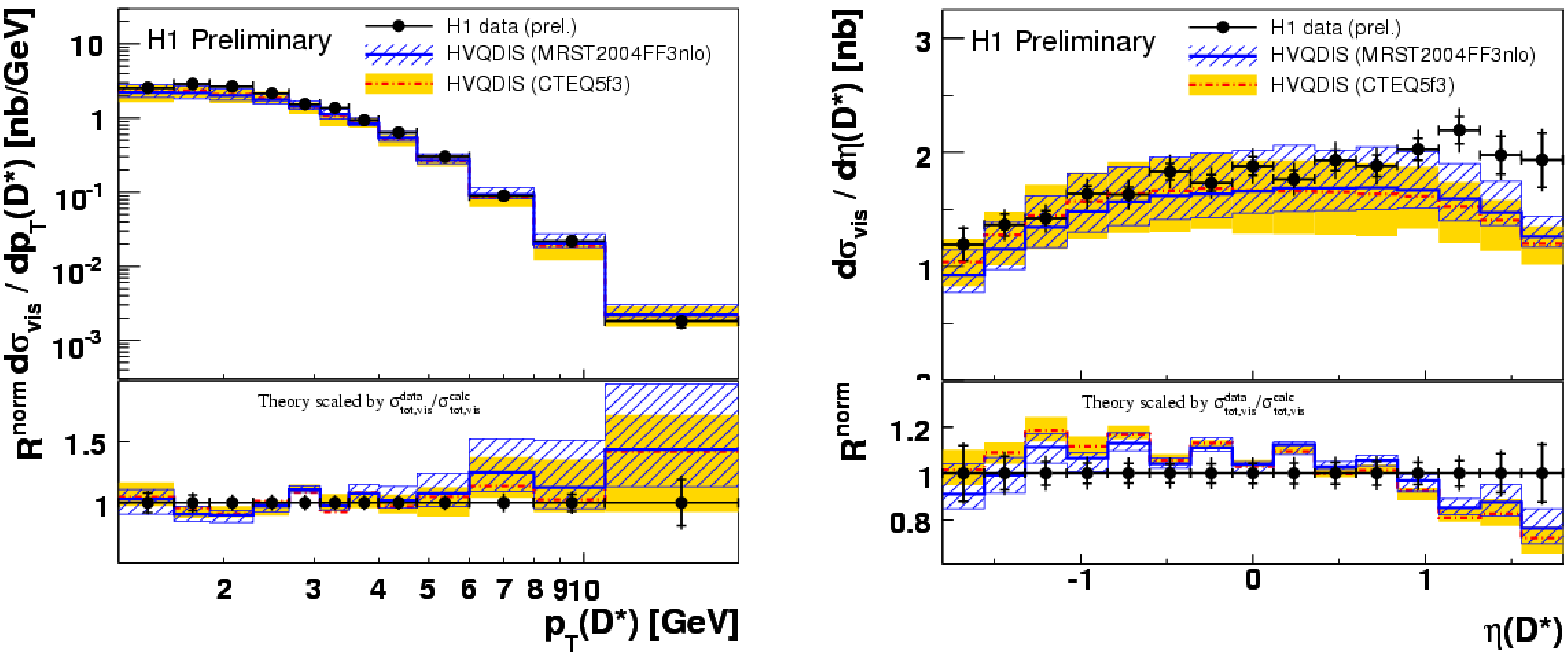
➔ Good description of data by NLO calculation (HVQDIS) over four orders of magnitude in Q^2

D* Meson Cross Sections

$\mathcal{L}$=347 pb^{-1}

$5 < Q^2 < 100$ GeV^2 , $0.02 < y < 0.7$
$p_t(D^*) > 1.25$ GeV, $|\eta(D^*)| < 1.8$

H1Prelim-10-172



- NLO calculations describe measured cross sections reasonably well

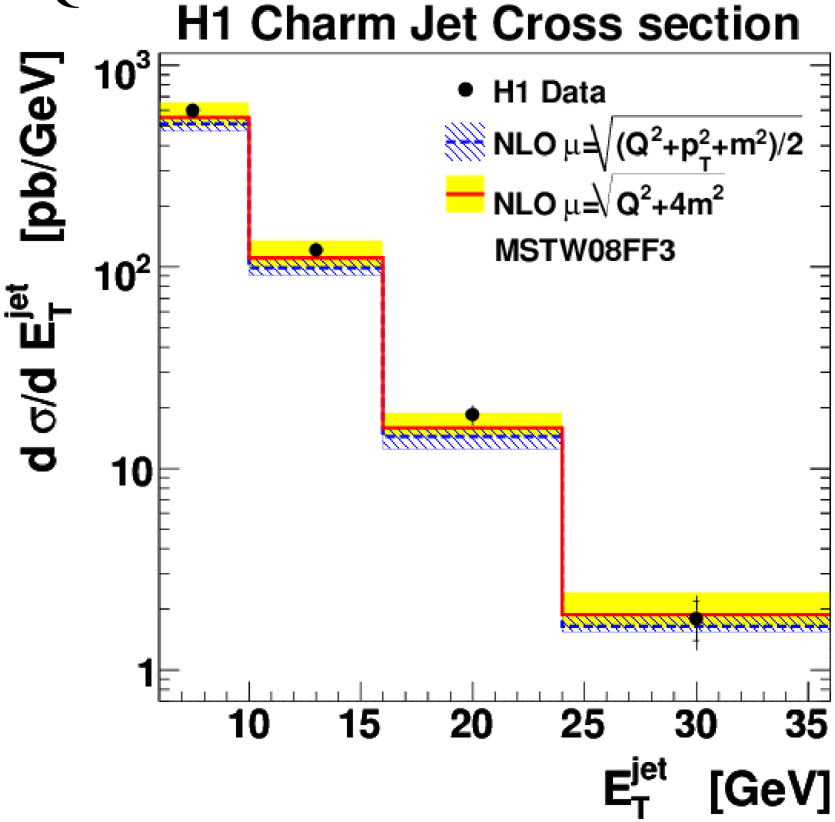
Charm Jet Cross Sections DIS

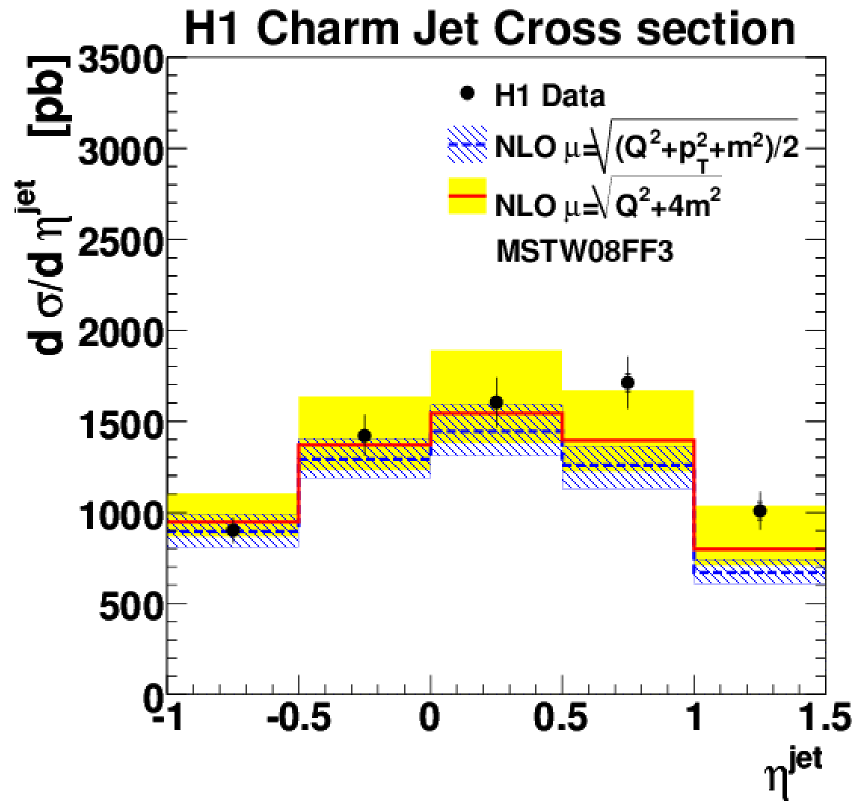
- Flavour separation: combine secondary vertex and impact parameter information
- Compare data with NLO calculation HVQDIS

$Q^2 > 6\ \text{GeV}^2$, $0.07 < y < 0.6$
$E_t^{jet} > 6$ GeV, $-1 < \eta_{jet} < 1.5$

H1: DESY-10-083

$\mathscr{L} = 189\ \text{pb}^{-1}$



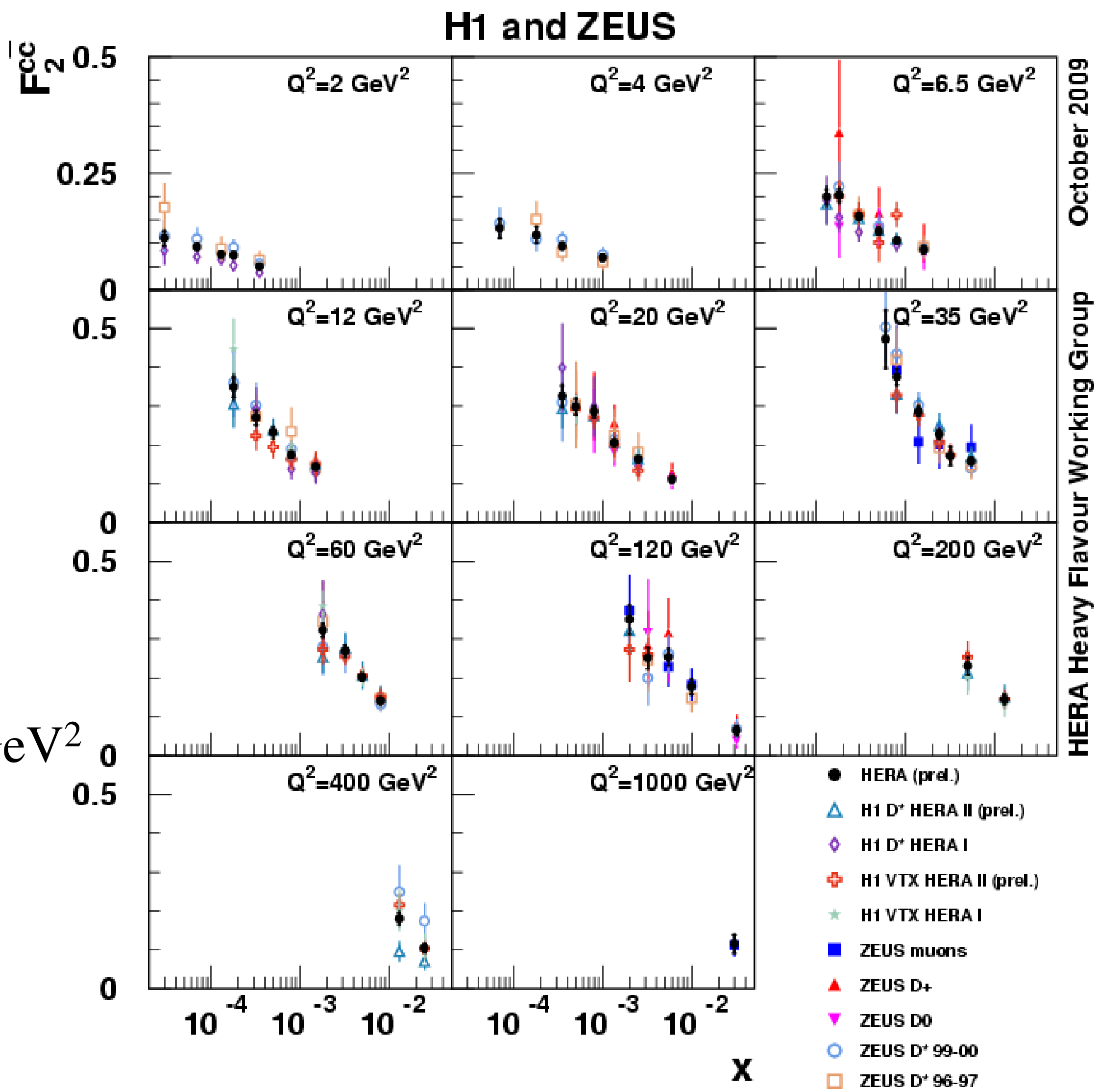


→ NLO QCD calculation provides reasonable description of data

→ Slight sensitivity to scale (large η)

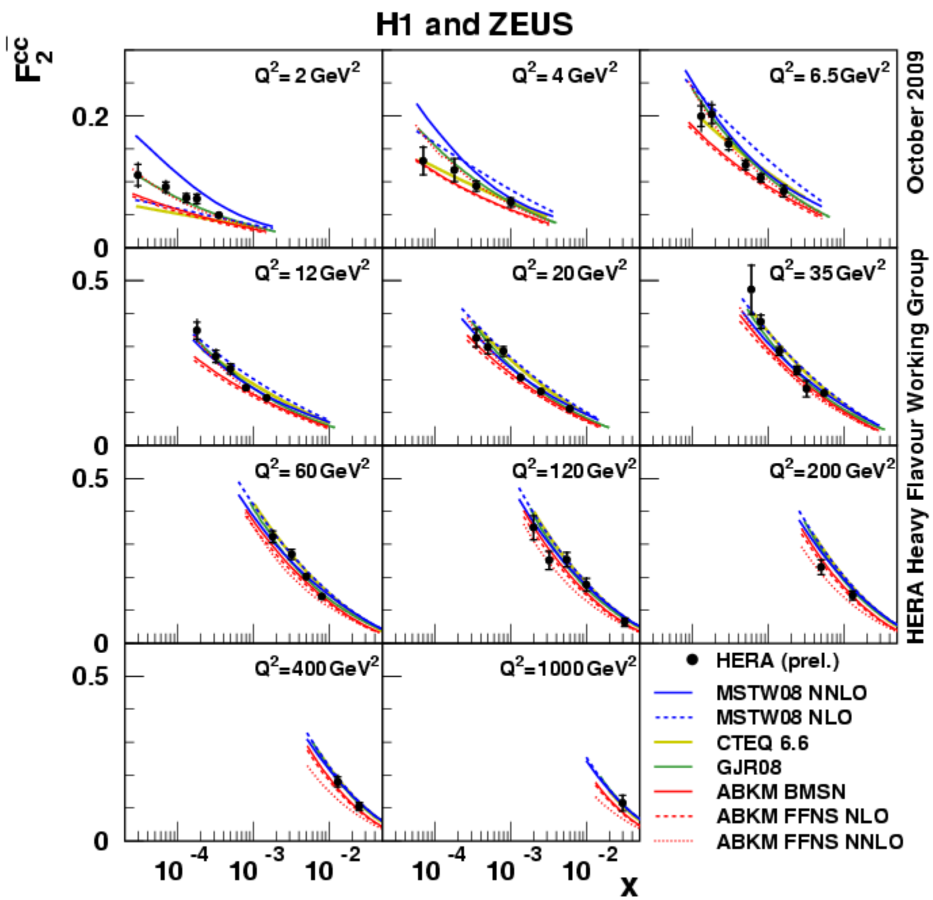
H1-ZEUS F_2^{cc} combination

- Combined F_2^{cc} compared to single measurements from H1 and ZEUS
- For combination take correlated systematic uncertainties into account
- Precision 5 – 10% for $6.5 < Q^2 < 60$ GeV^2

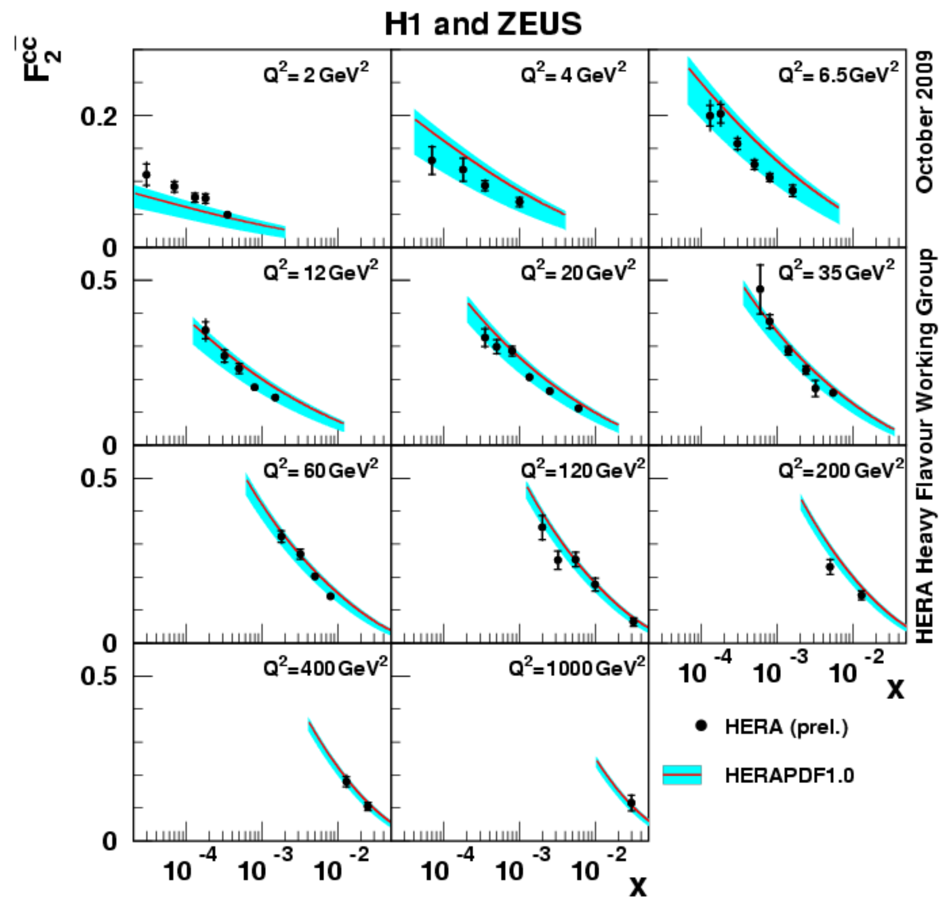


H1-ZEUS F_2^{cc} combination

- Combined F_2^{cc} compared to NLO and NNLO calculations



- Combined F_2^{cc} compared to HERAPDF 1.0



➔ Precision in data good enough to discriminate between different theory predictions

Summary

- Jet physics at HERA provides precision measurements to understand QCD
- Precise and consistent extraction of strong coupling constant and its running over wide range of scale in one experiment

- Measured charm and beauty cross sections in general in good agreement with NLO QCD
- Different beauty measurements provide consistent results of F_2^{bb}
- Predictions from NLO QCD describe measured F_2^{bb}
- Combining H1 and ZEUS F_2^{cc} measurements provide a precision of 5 – 10 % on a wide kinematic range