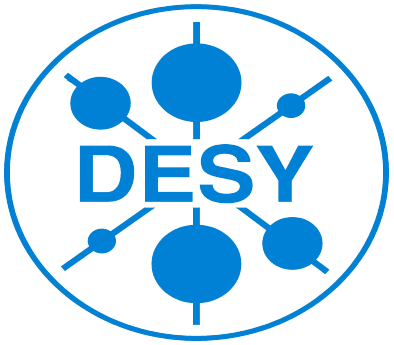
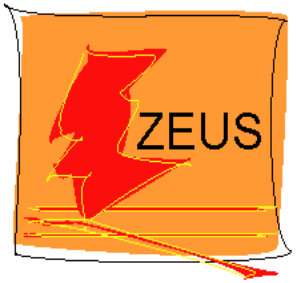


Charm production at HERA

Vladyslav Libov (DESY)
on behalf of H1 and ZEUS collaborations

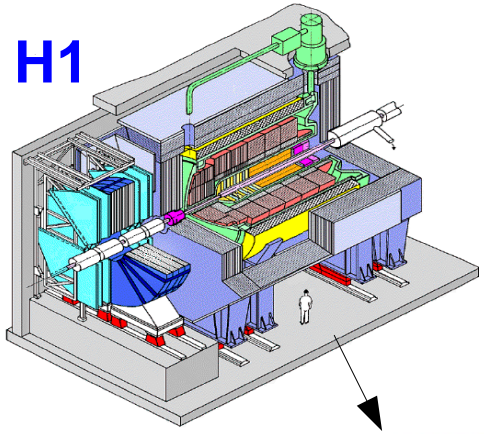


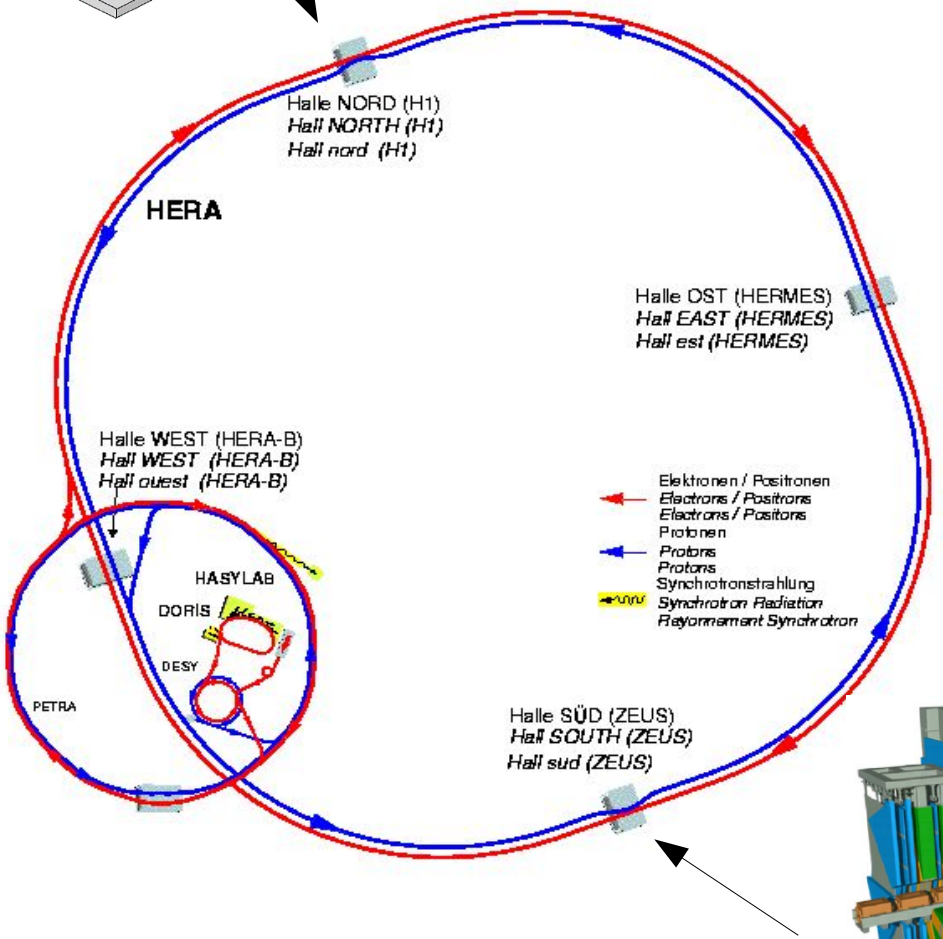
Outline

- Physics of charm production at HERA
- Experimental methods of charm tagging
- Recent charm results
- Summary and outlook

Low x Meeting 2010, June 23-27, Kavala, Greece

HERA collider

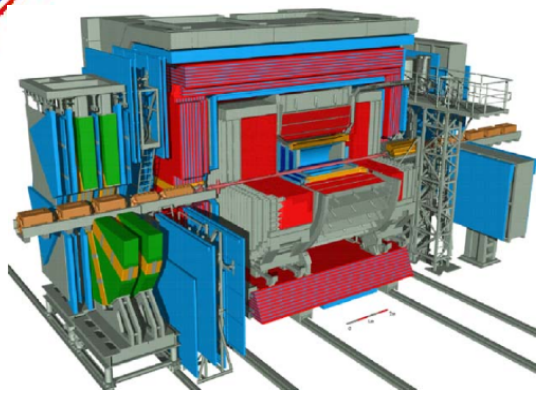




- Protons 920 GeV
- Electrons 27.6 GeV

$\sqrt{s} = 318\,GeV$

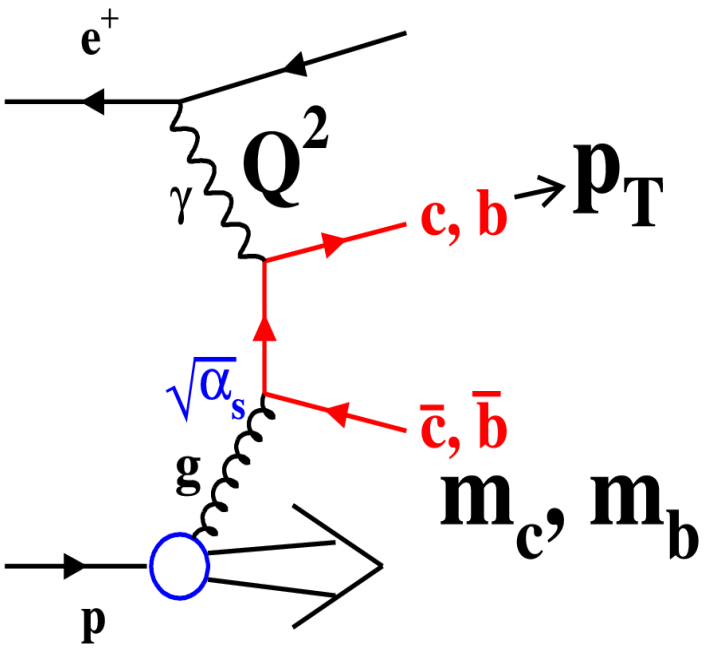
- Operational: 1992-2007
- H1 and ZEUS – general purpose hermetic detectors
- ~500 pb^{-1} per experiment accumulated during HERA I and HERA II running periods



ZEUS

Charm physics at HERA

- Heavy flavours are produced in the LO via Boson-Gluon Fusion (BGF)
- Sensitivity to the gluon density in the proton
- High charm mass allows pQCD calculations to be performed and tested by comparing with data
- Multi-hard-scale problem (m_c, p_T, Q^2)



Kinematics of ep scattering:

$$Q^2 = -q^2 = -(k - k')^2$$

$$x = \frac{Q^2}{2P \cdot q}$$

$$y = \frac{P \cdot q}{P \cdot k}$$

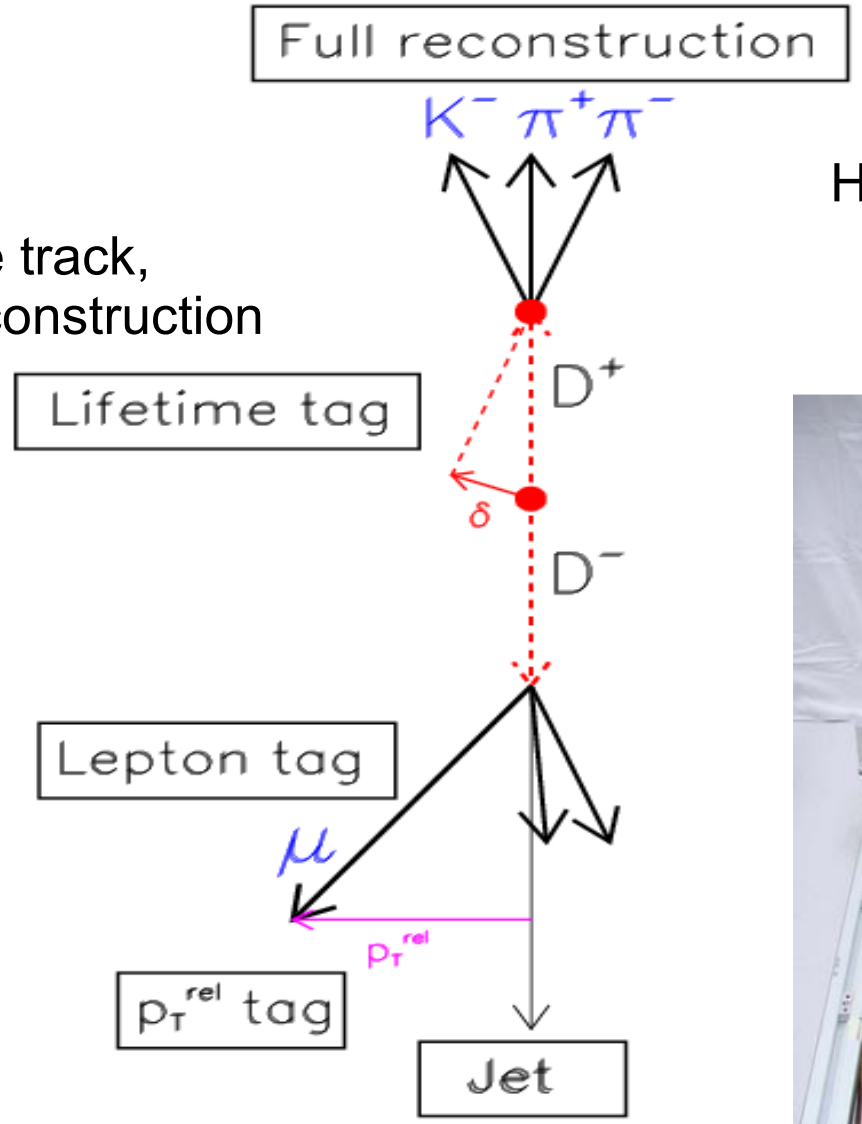
- PHP: $Q^2 \sim 0$ GeV^2
- DIS: $Q^2 > 1$ GeV^2

- NLO QCD calculations
  - Massive scheme (FFNS): HVQDIS, FMNR
  - Massless scheme (ZMVFNS)
  - Mixed schemes (GMVFNS)
- NNLO partially available

Charm tagging methods

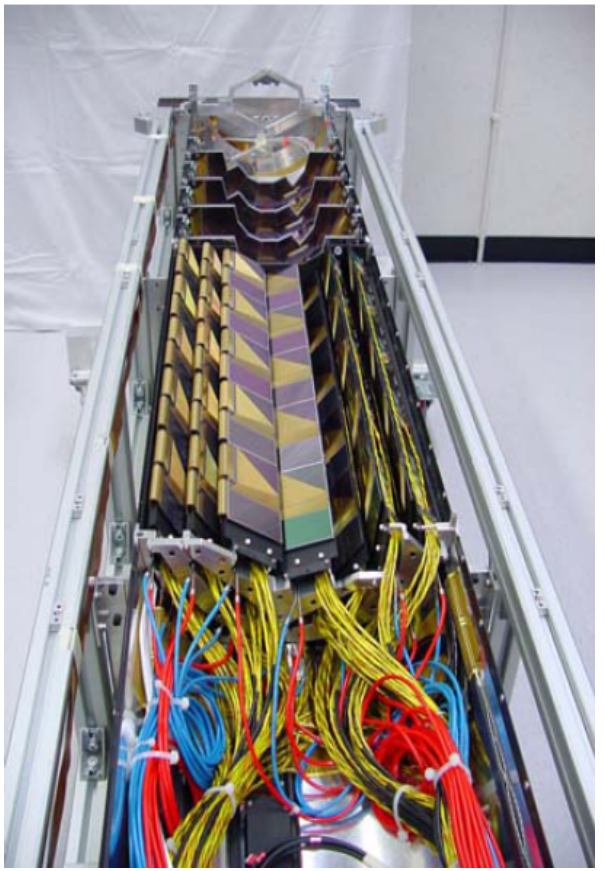
D^+, D^*, D^0 mesons

Impact parameter of the track, secondary vertex reconstruction



Tags hard parton

High resolution vertex detectors are crucial for lifetime tagging

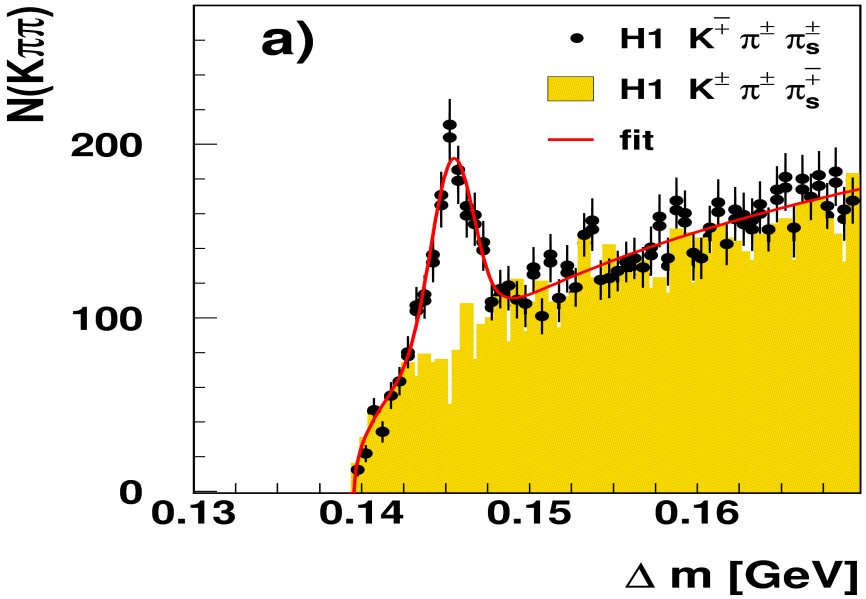


- Methods can be combined
- Can be used for *single* or *double* tagging

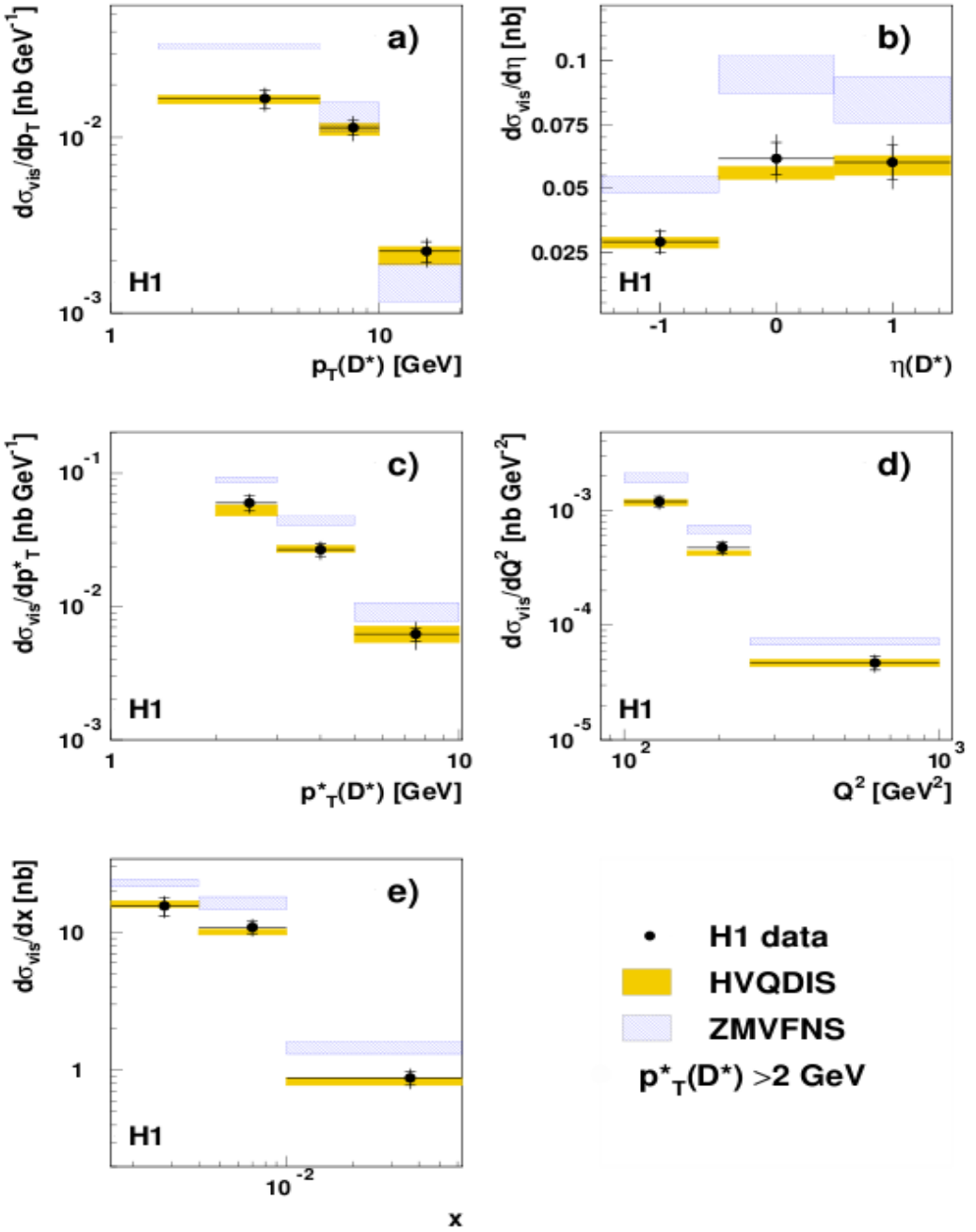
D* measurement in DIS at high Q^2

- $100 < Q^2 < 1000$ GeV^2
- "Golden" decay channel:

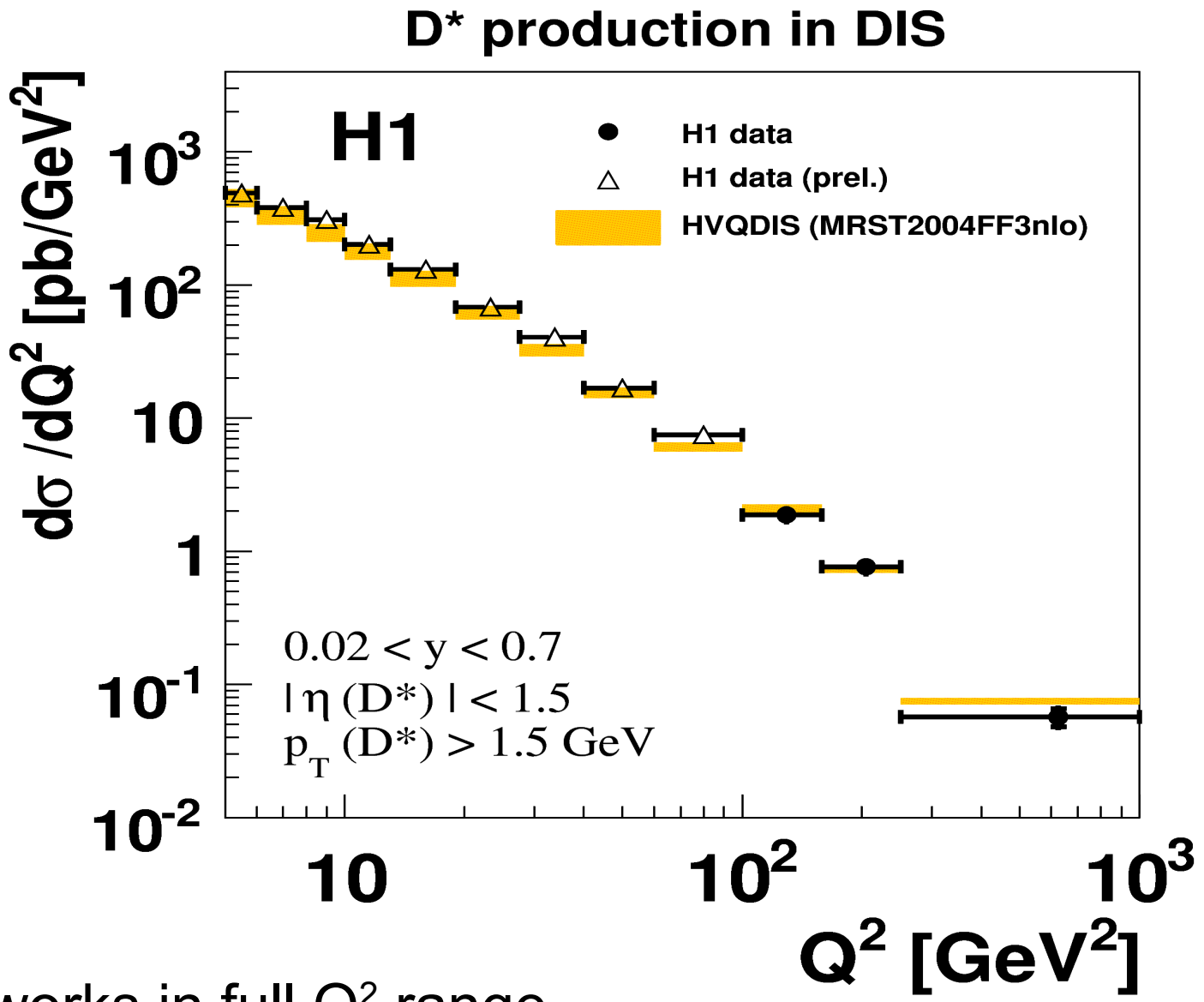
$$D^* \rightarrow D^0 \pi_s \rightarrow K\pi\pi_s$$



- HVQDIS describes data well
- ZMVFNS fails to describe data even at high Q^2 (not only in normalization but also in shape)



Phys.Lett.B 686: 91-100, 2010



- HVQDIS works in full Q^2 range

Phys.Lett.B 686: 91-100, 2010

H1prelim08-72

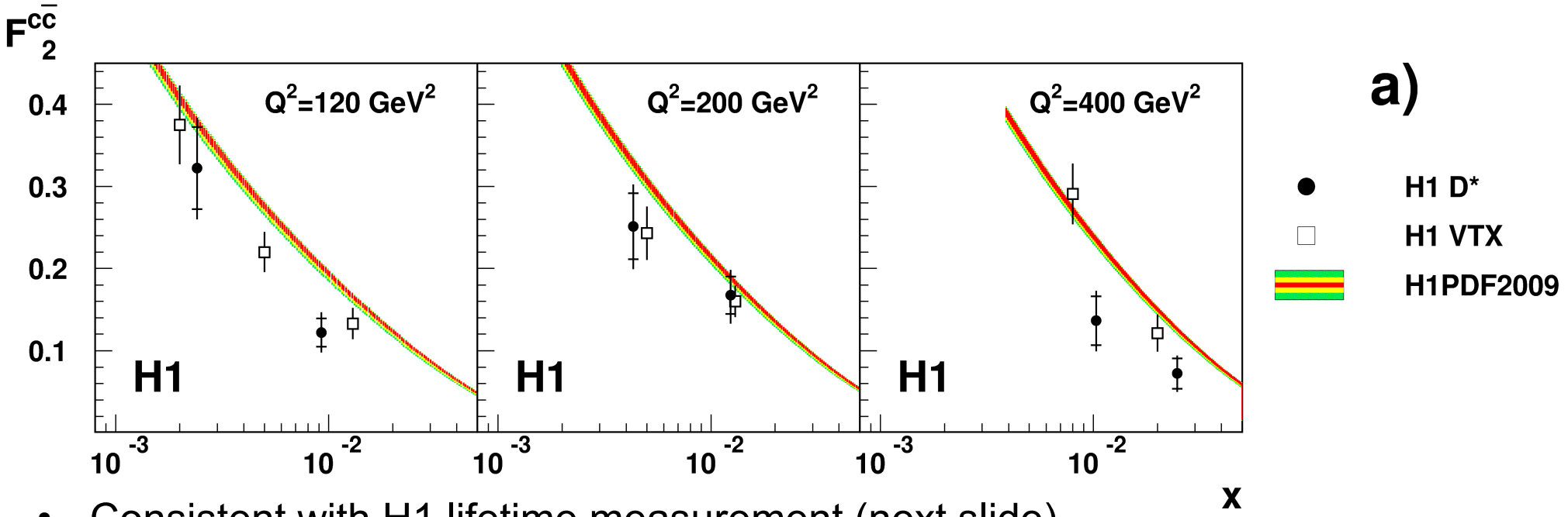
D* measurement in DIS at high Q^2: F_2^{cc}

- Charm structure function (neglecting F_L)

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

- NLO QCD to extrapolate to full phase space:

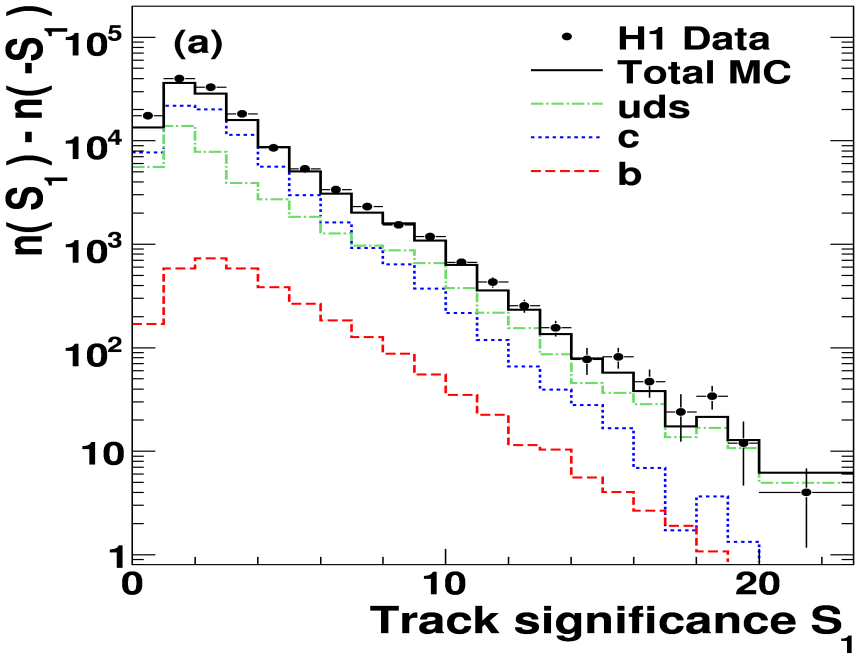
$$F_2^{c\bar{c}}(\exp) = \frac{\sigma_{vis}(\exp)}{\sigma_{vis}(theory)} F_2^{c\bar{c}}(theory)$$

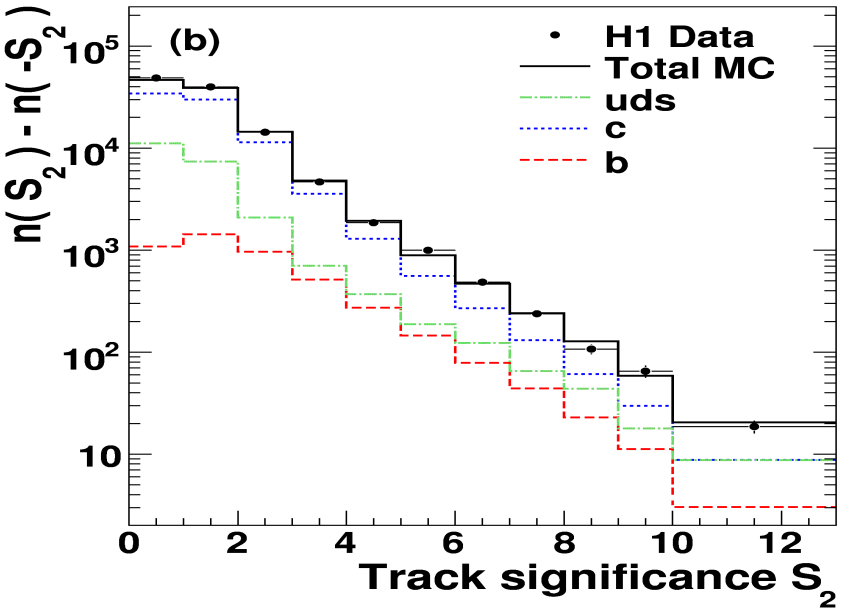


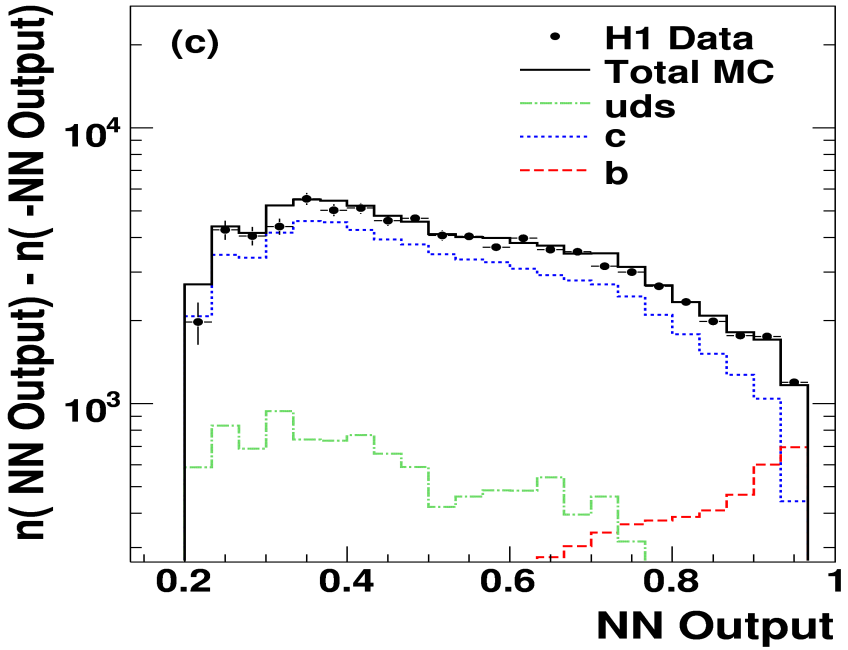
- Consistent with H1 lifetime measurement (next slide)

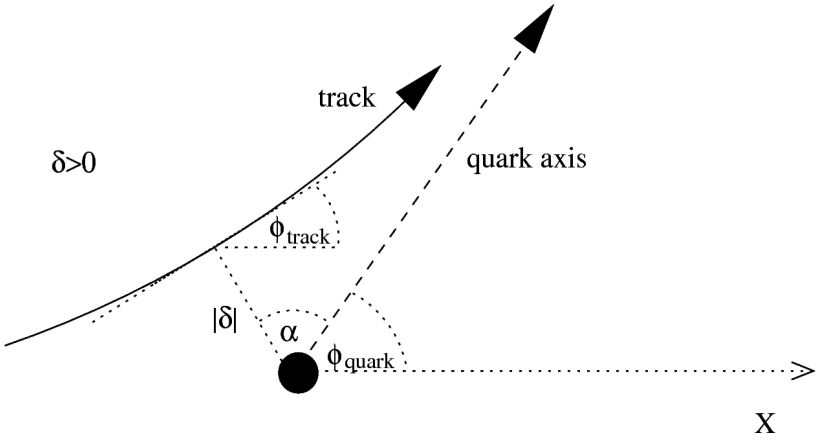
Phys.Lett.B 686: 91-100, 2010

Inclusive lifetime measurement: method









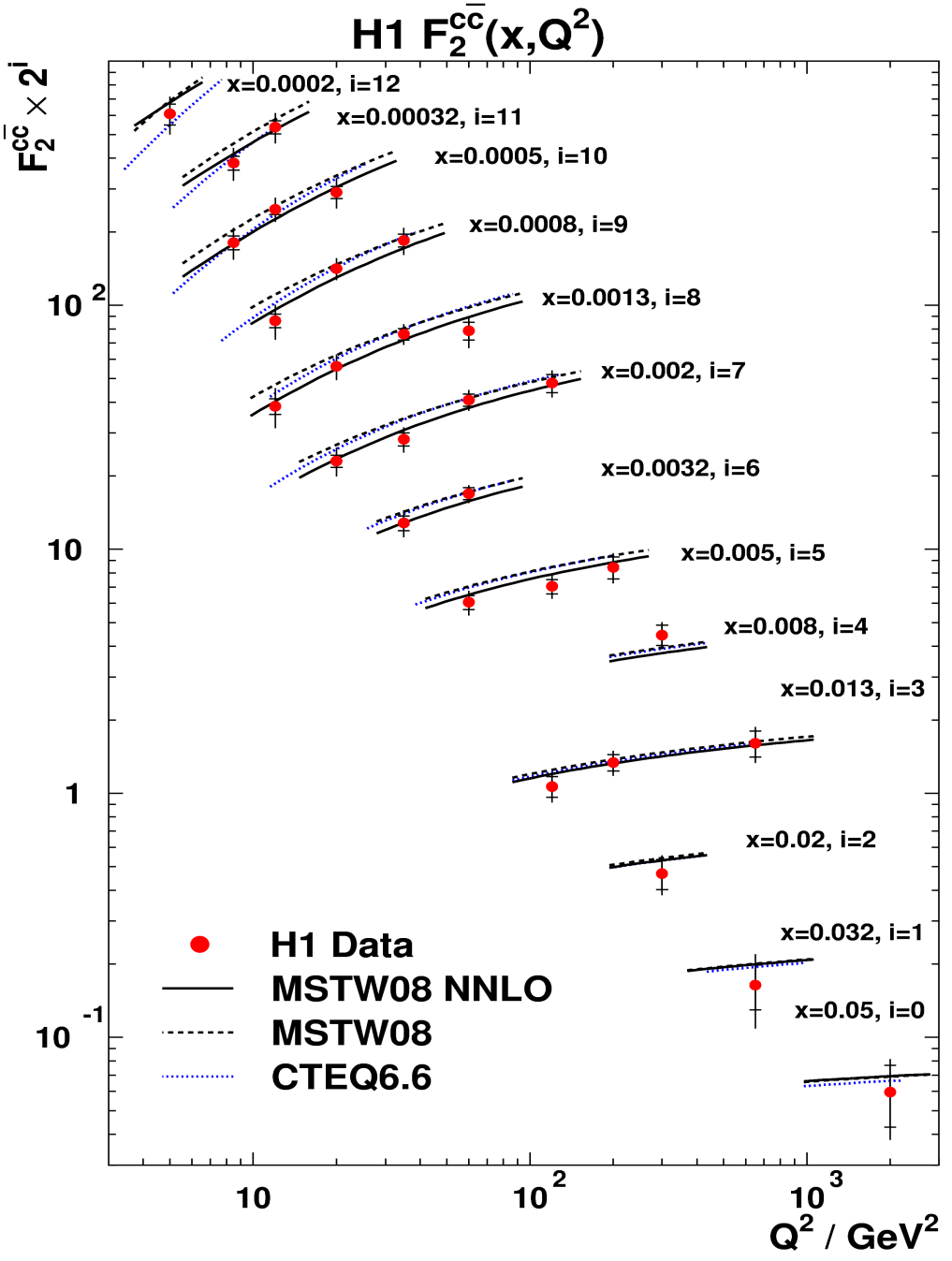
S_1, S_2 and NN are fitted simultaneously

- Results on beauty – talk by Michel Sauter

Eur.Phys.J.C65:89-109, 2010

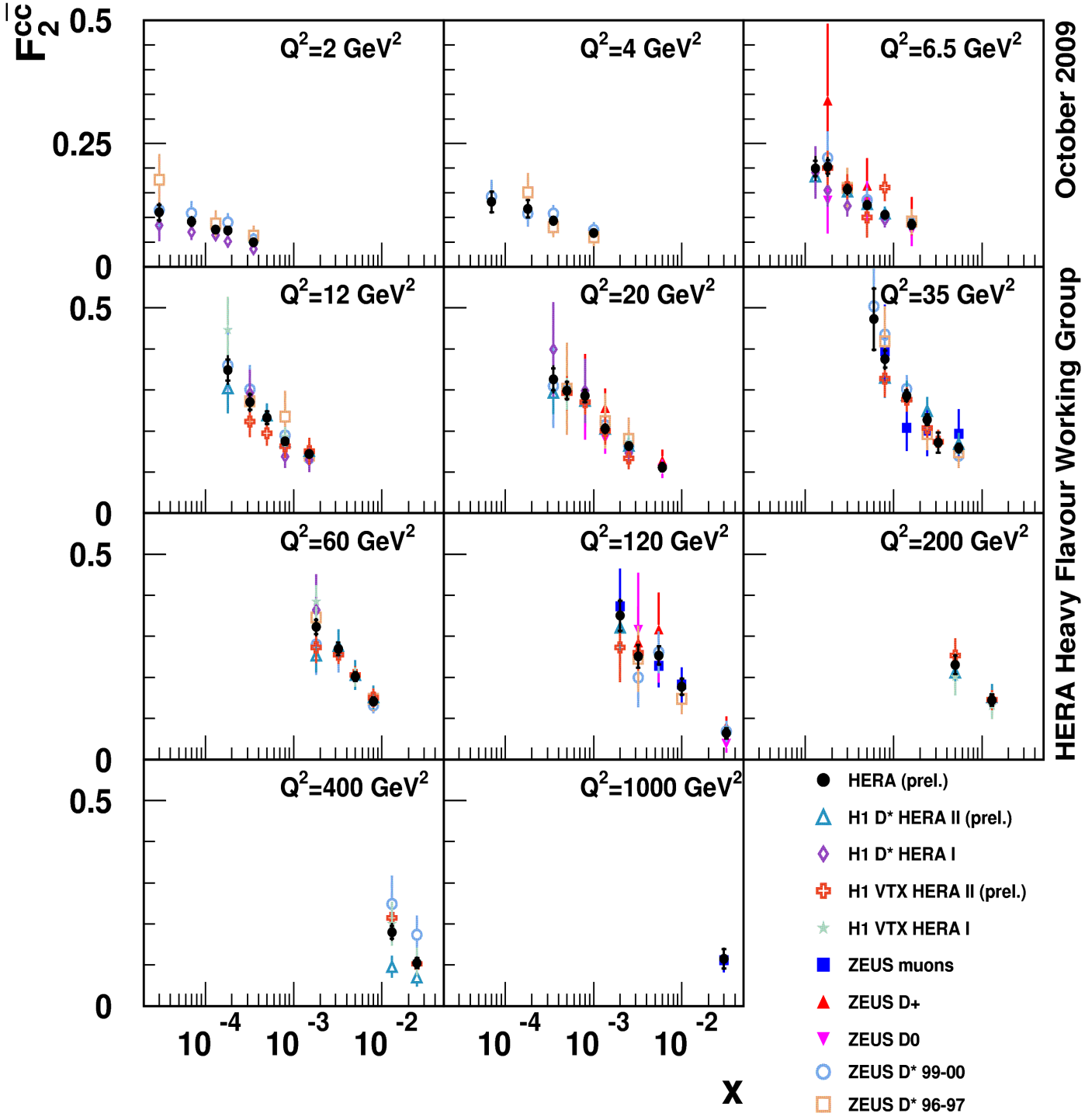
Inclusive lifetime measurement: F_2^{cc}

- decription by MSTW QCD is reasonable, NNLO somewhat better than NLO
- CTEQ NLO – also gives a reasonable description



Eur.Phys.J.C65:89-109, 2010

H1+ZEUS F_2^{cc} combination



ZEUS-prel-09-015

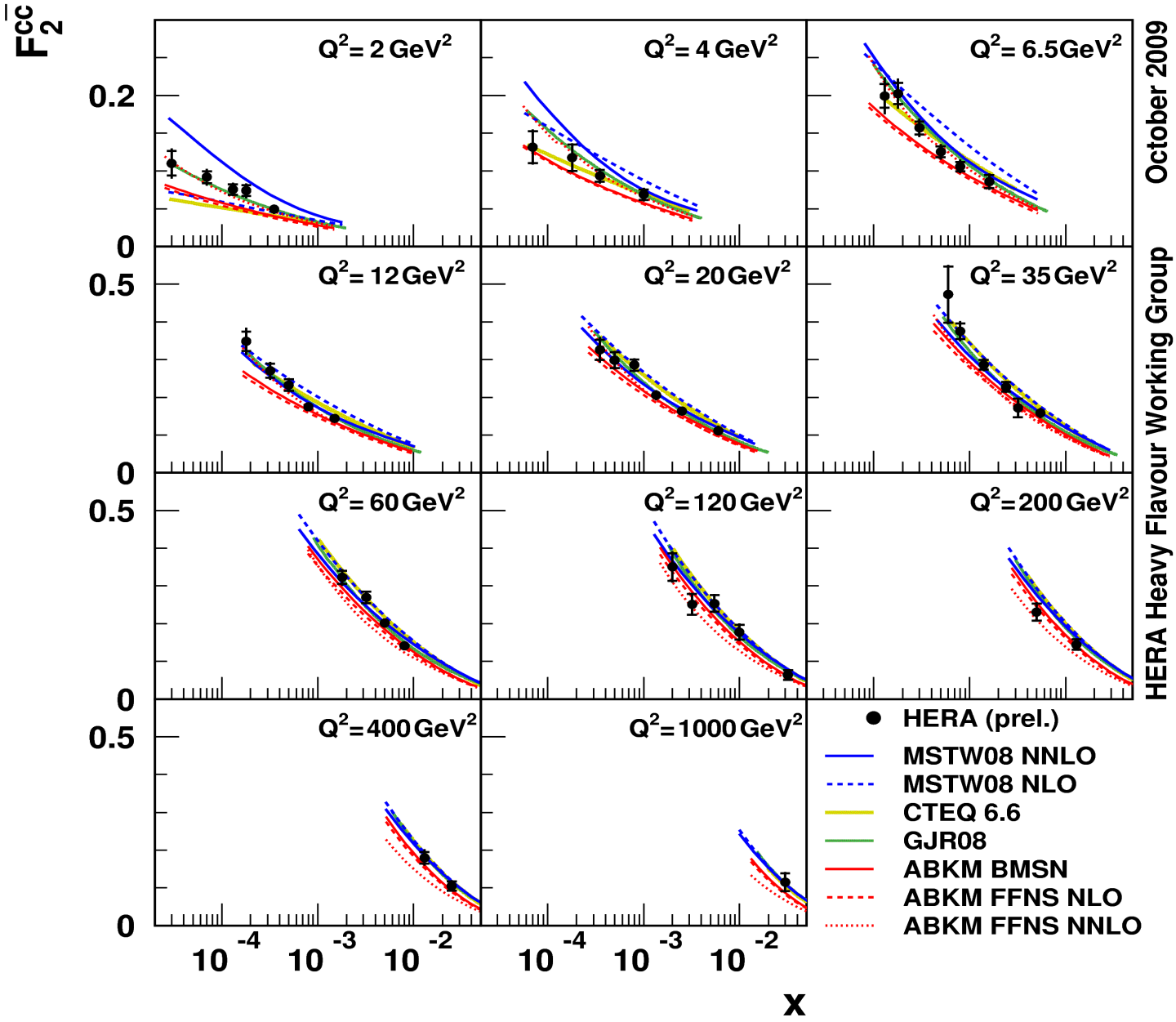
H1prelim-09-171

- Measurements are combined taking into account correlated systematic uncertainties
- Average precision 5-10%

H1+ZEUS F_2^{cc} combination

ZEUS-prel-09-015

H1prelim-09-171

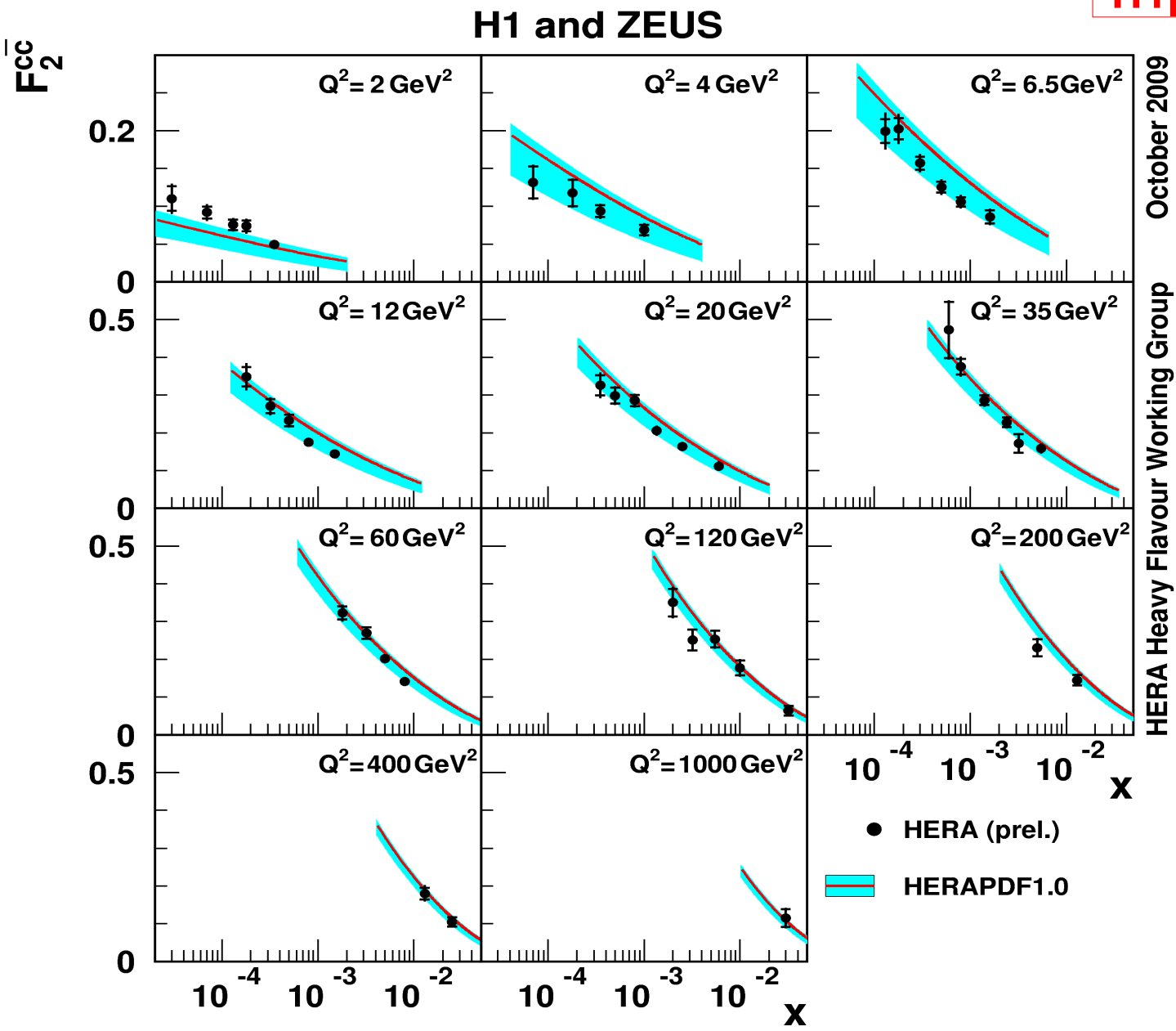


- The precision of combined data is smaller than spread between predictions

H1+ZEUS F_2^{cc} combination

ZEUS-prel-09-015

H1prelim-09-171



- Charm data may help to constrain PDFs, see talk by Voica Radescu

Measurement of D^+ in DIS

- $D^+ \rightarrow K^-\pi^+\pi^+$ decay channel is used
- Decay vertex is fully reconstructed

ZEUS-prel-10-005

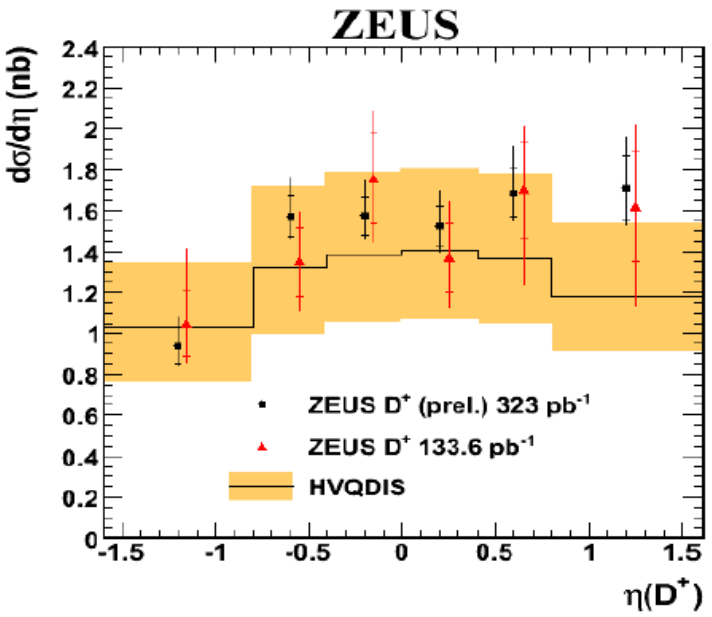
- Kinematic region:

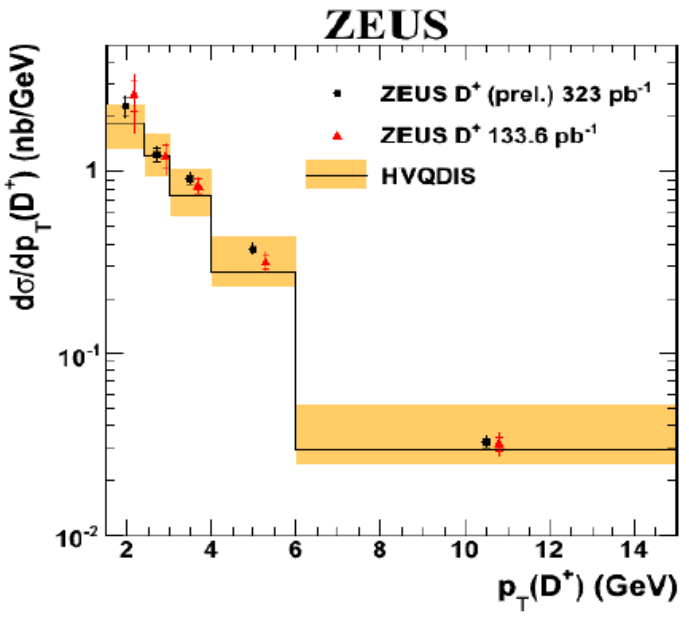
$5 < Q^2 < 1000\ GeV^2$

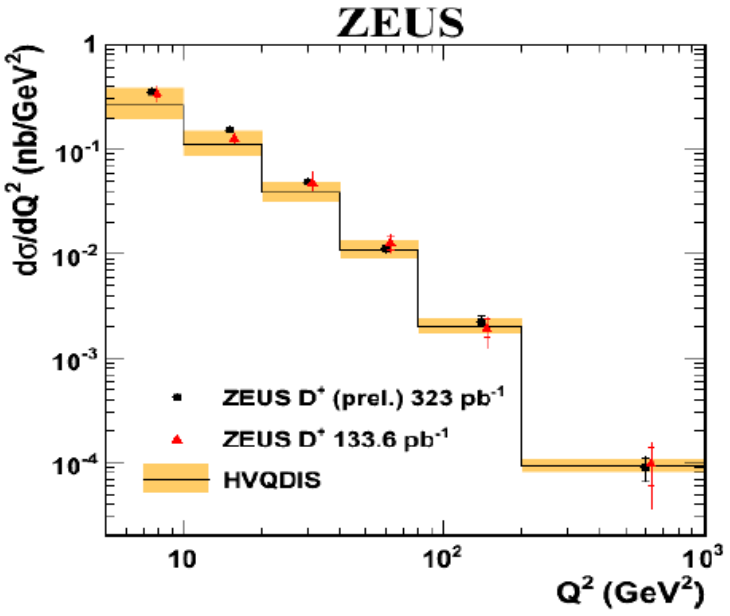
$0.02 < y < 0.7$

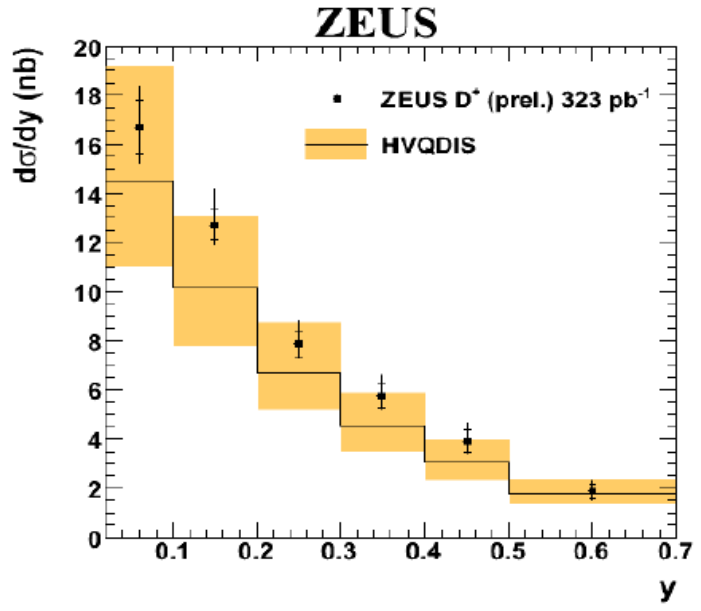
$1.5 < p_T(D^+) < 15\ GeV$

$|\eta(D^+)| < 1.6$







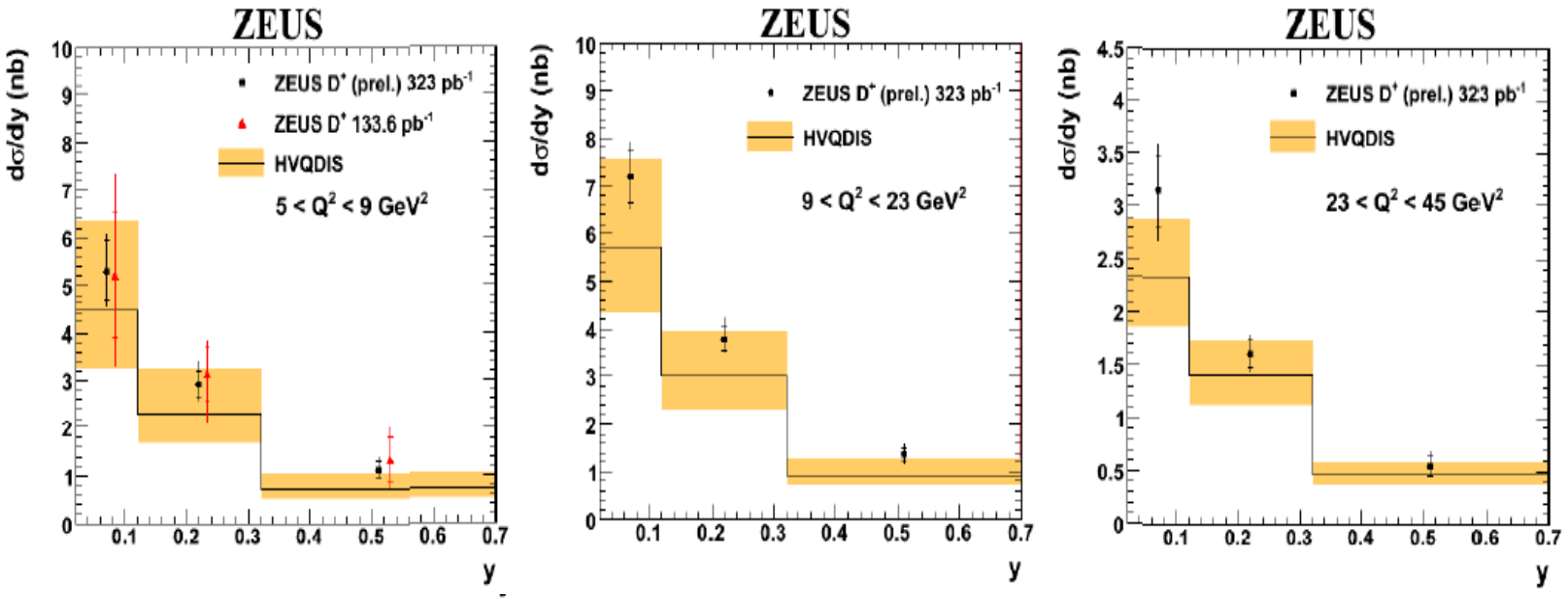


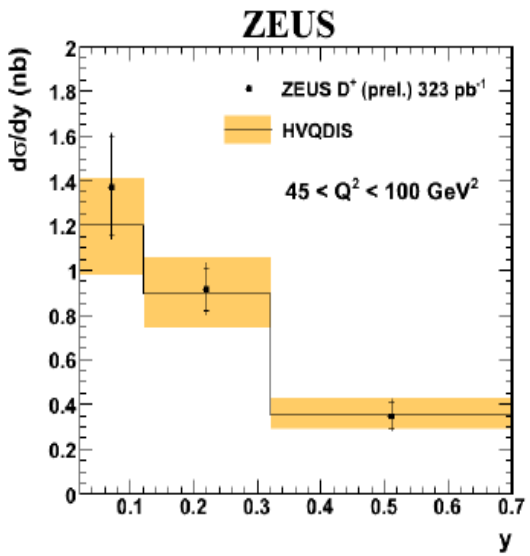
- Much larger statistics → precision improved
- Data consistent with previous ZEUS results
- Good description by HVQDIS

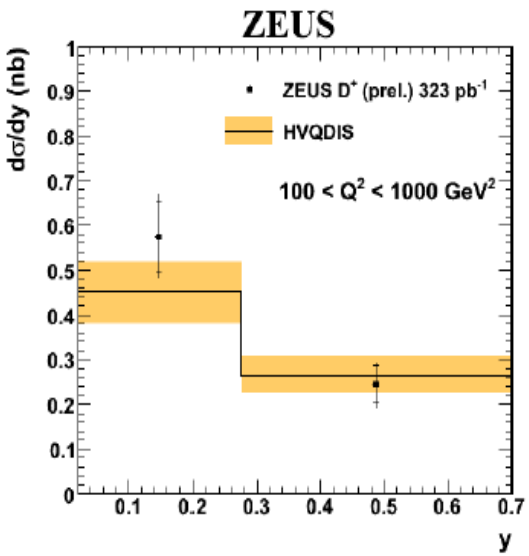
Measurement of D^+ in DIS

- Double differential cross-sections – used as input to F_2^{cc} calculations

ZEUS-prel-10-005



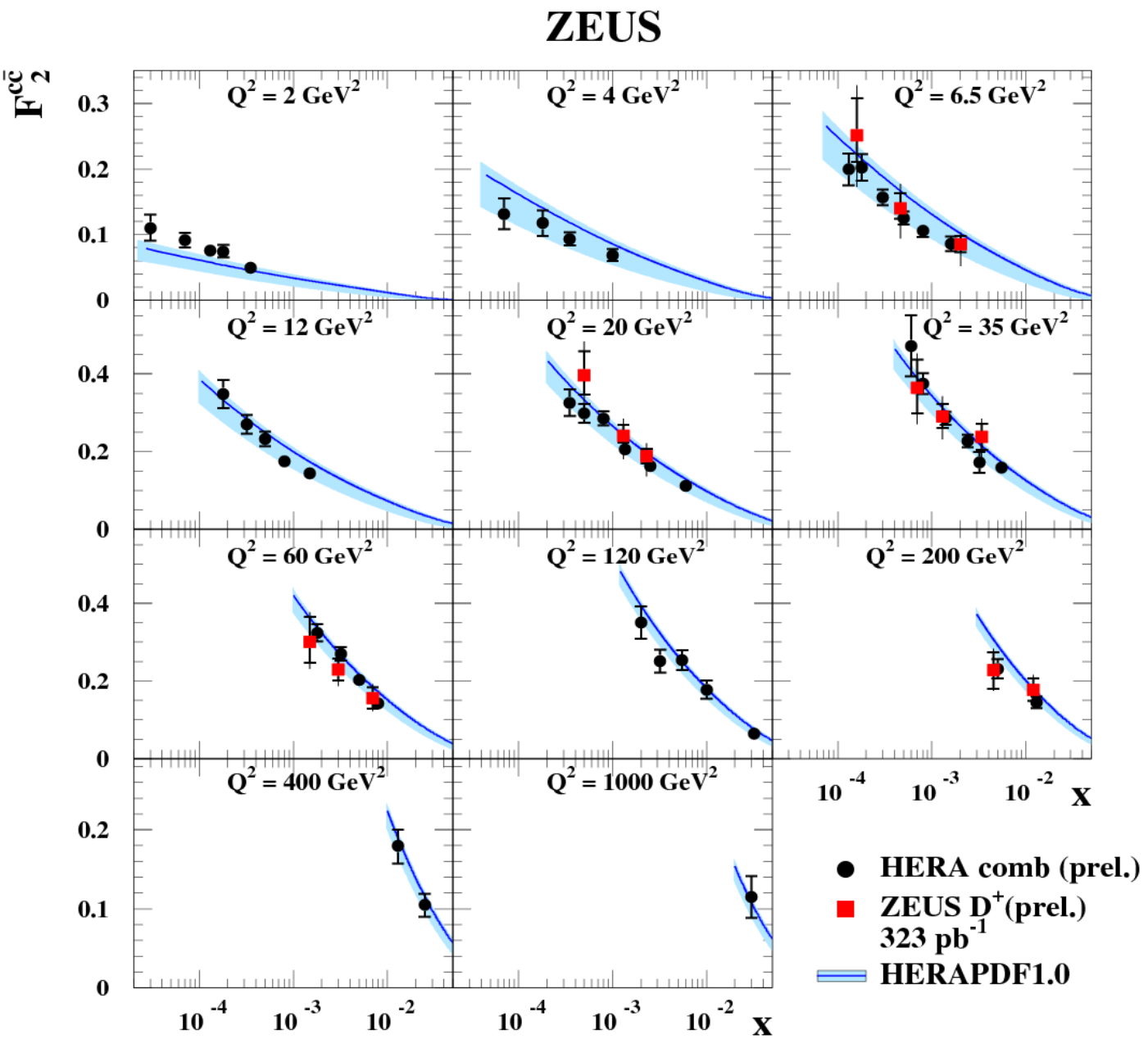




- Described well by HVQDIS

Measurement of D^+ in DIS: F_2^{cc}

ZEUS-prel-10-005

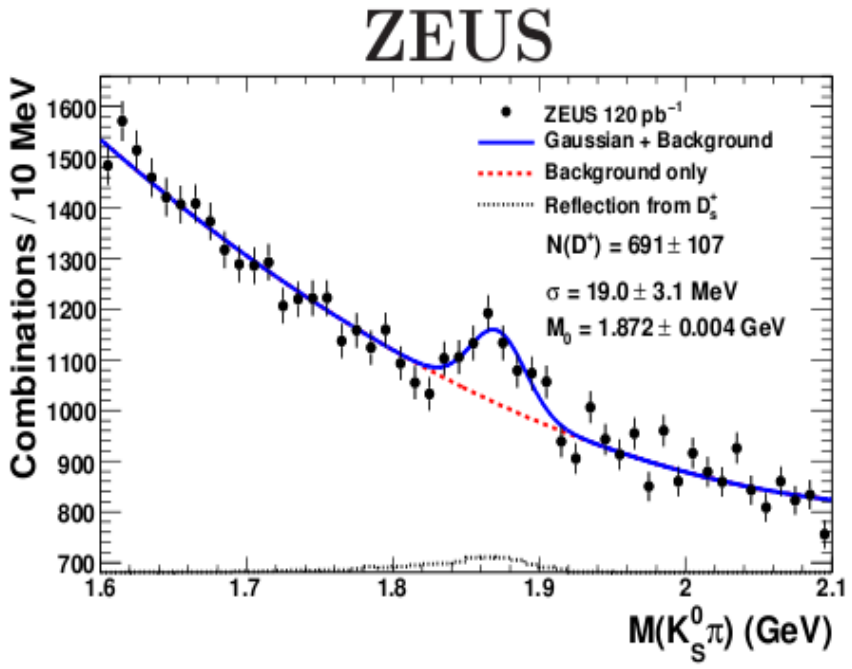


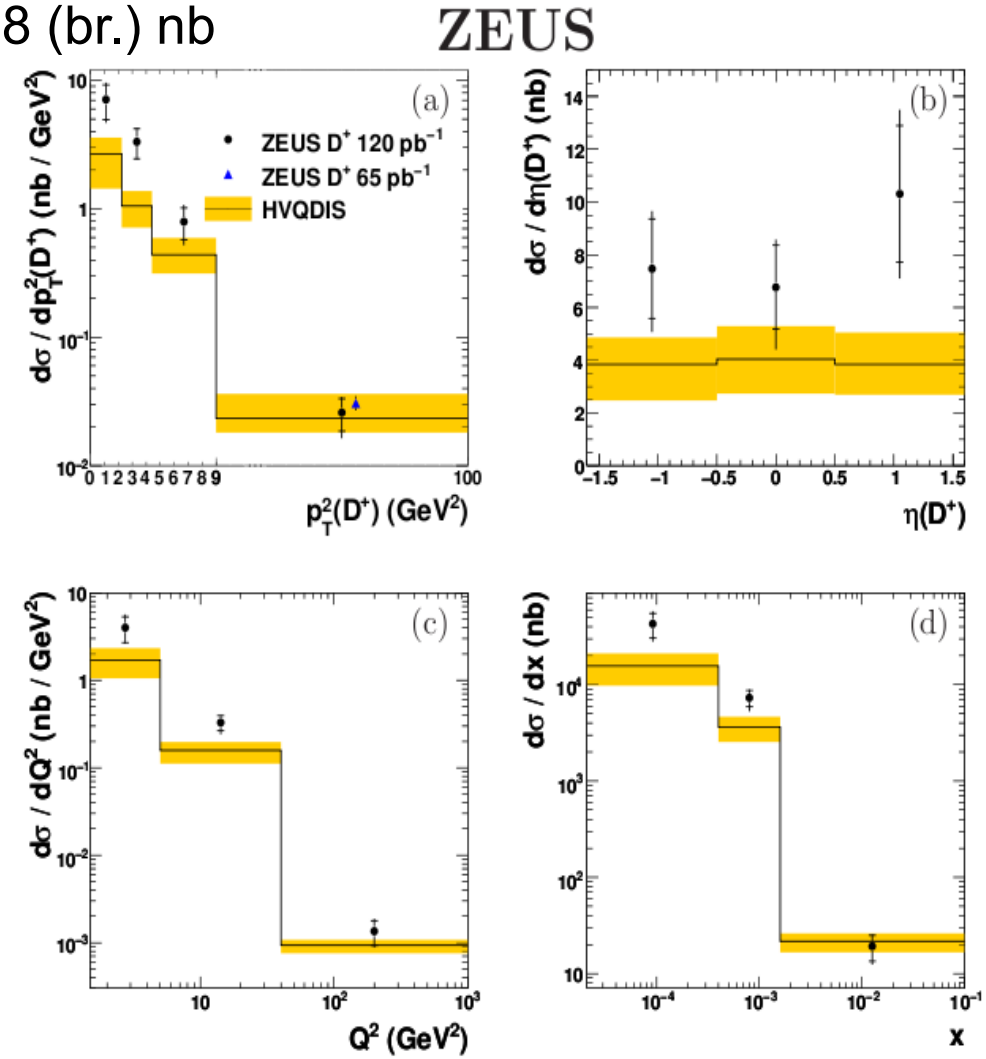
- New data are consistent with HERA combined results
- Will be used in the future for the comnbination

Measurement of D^+ and Λ_c^+ production in DIS

DESY-10-064, to be publ. in JHEP

- $D^+ \to K^0_S \pi^+$ decay channel is used (+ c.c.)
- $\sigma(D^+) = 25.7 \pm 4.1\ (\text{stat.})\ ^{+3.8}_{-5.2}\ (\text{syst.}) \pm 0.8\ (\text{br.})$ nb
- HVQDIS: $\sigma(D^+) = 12.7\ ^{+3.8}_{-4.1}$ nb



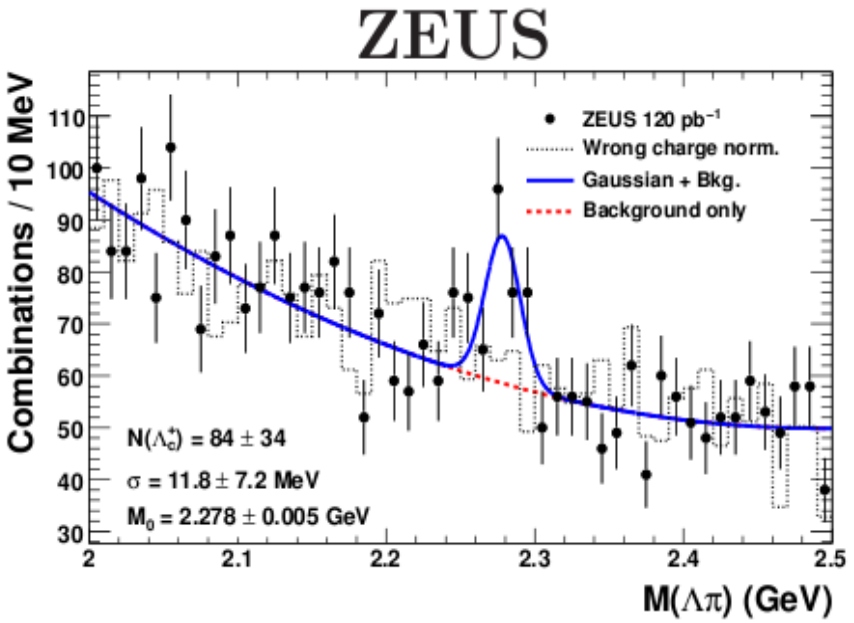


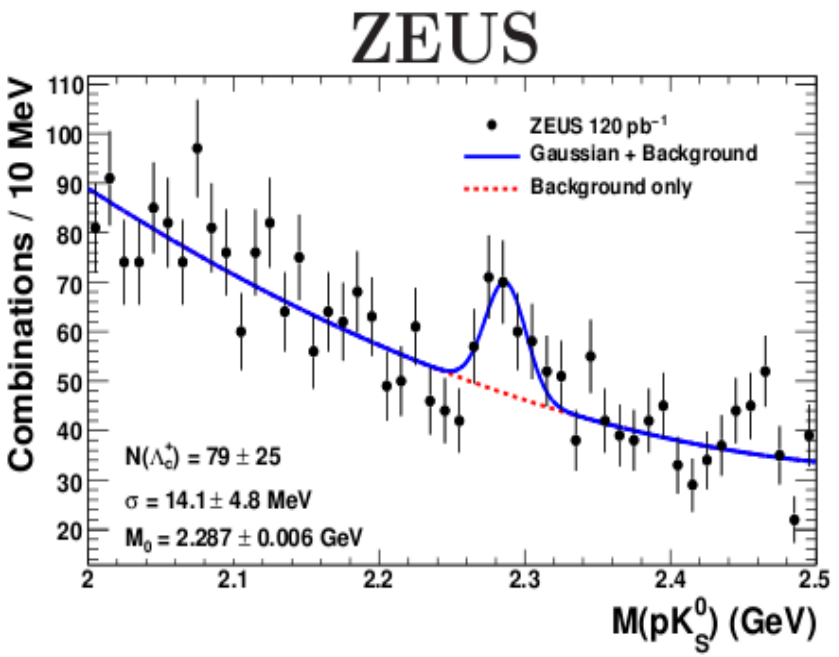
- Measured phase space extended to lower p_T
- Cross-sections described reasonably by HVQDIS

Measurement of D^+ and Λ_c^+ production in DIS

DESY-10-064, to be publ. in JHEP

- Λ_c are reconstructed in $\Lambda\pi$ and pK_0^S modes





- $\sigma_{combined}(\Lambda_c^+) = 14.7 \pm 3.8\ (stat.)\ ^{+2.1}_{-2.2}\ (syst.) \pm 3.9\ (br.)$ nb
- Fragmentation fraction is measured for the first time in DIS at HERA

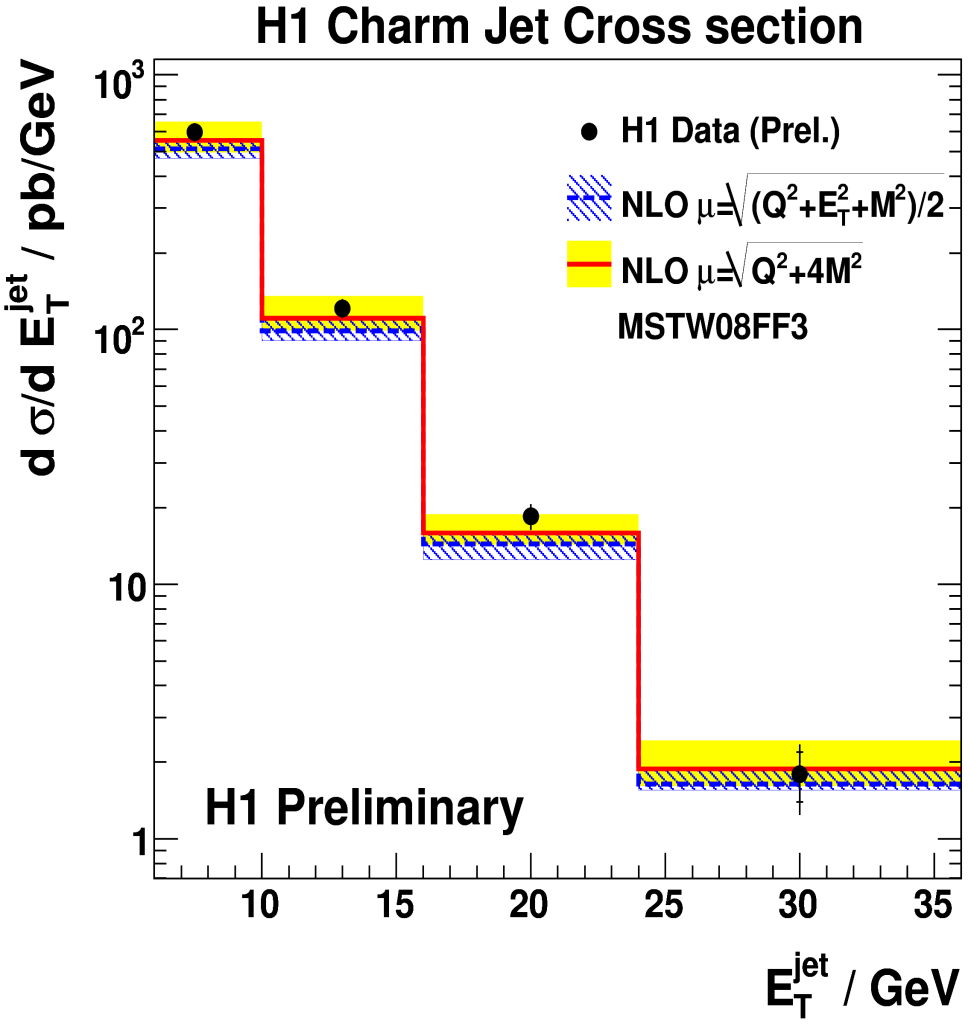
$$f(c \to \Lambda_c^+) = \frac{\sigma(\Lambda_c^+)}{\sigma(D^+)} f(c \to D^+)$$

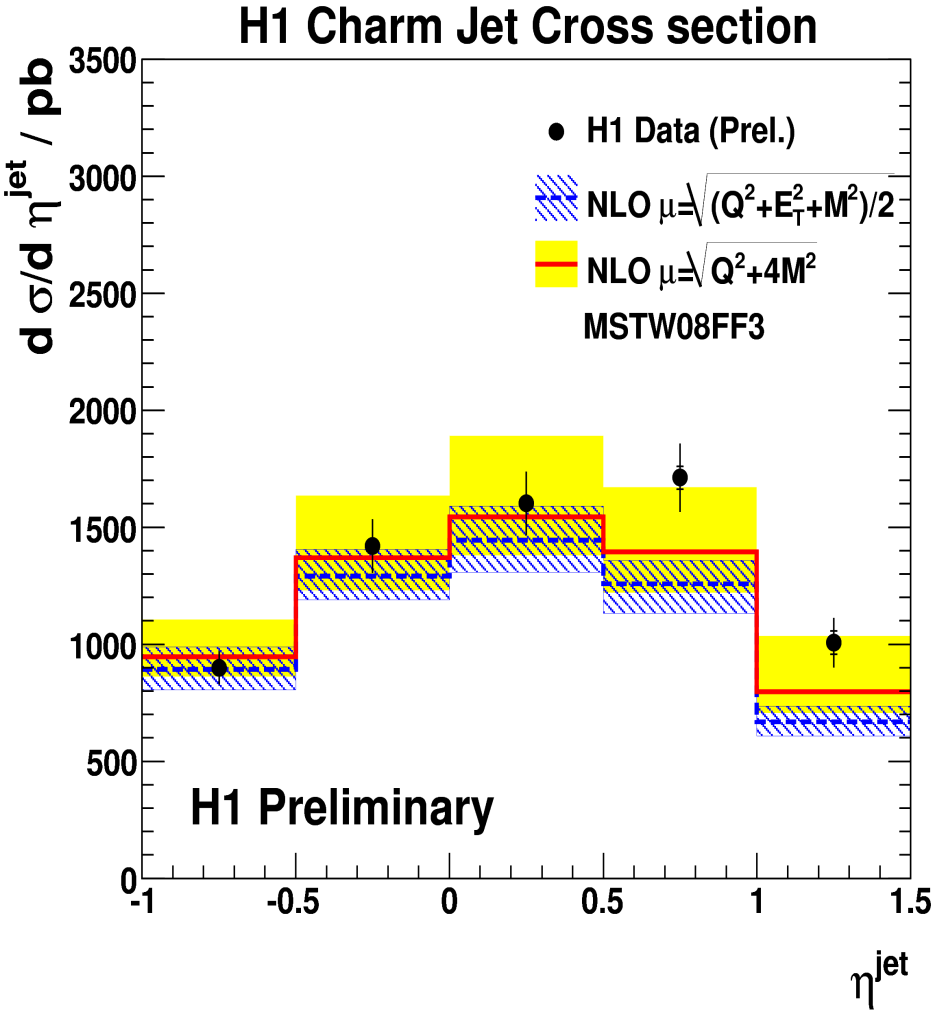
	$f(c \to \Lambda_c^+)$
ZEUS (DIS)	$0.117 \pm 0.033\ (stat.)\ ^{+0.026}_{-0.022}\ (syst.) \pm 0.027\ (br.)$
ZEUS (γp) [9]	$0.144 \pm 0.022\ (stat.)\ ^{+0.013}_{-0.022}\ (syst.)\ ^{+0.037}_{-0.025}\ (br.)$
combined e^+e^- data	$0.076 \pm 0.007\ (stat. \oplus syst.)\ ^{+0.027}_{-0.016}\ (br.)$

Measurement of Charm Jets in DIS

- Similar technique to Eur.Phys.J.C65:89-109, 2010 but with jet requirement

H1prelim-10-073



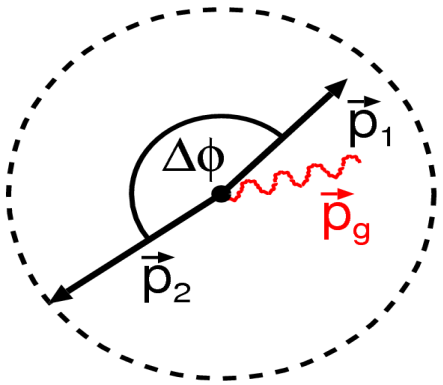


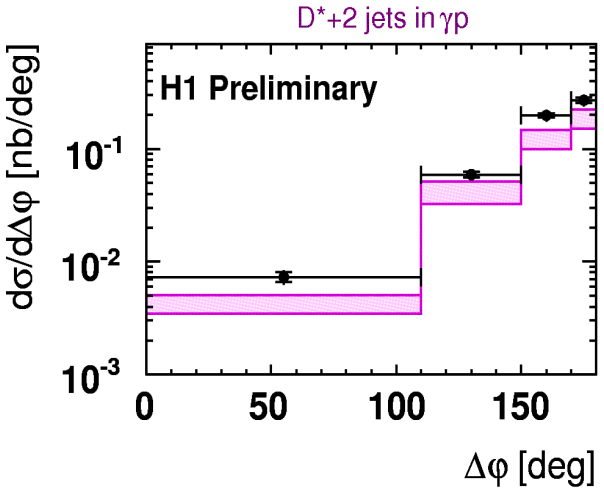
- Good agreement with NLO predictions
- More details – see talk by Michel Sauter

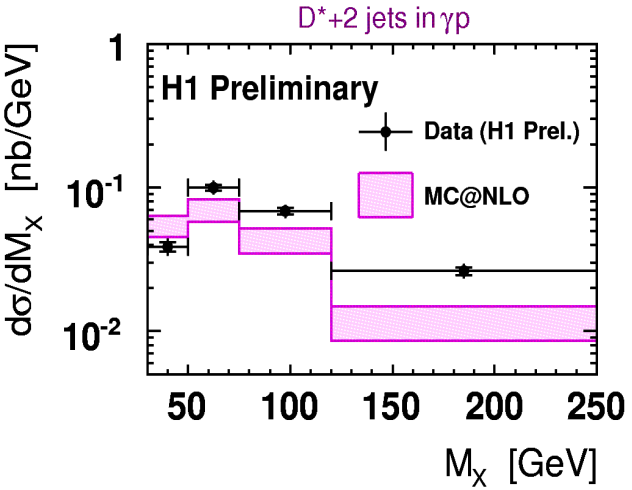
Photoproduction of D* with jets

H1prelim-10-072

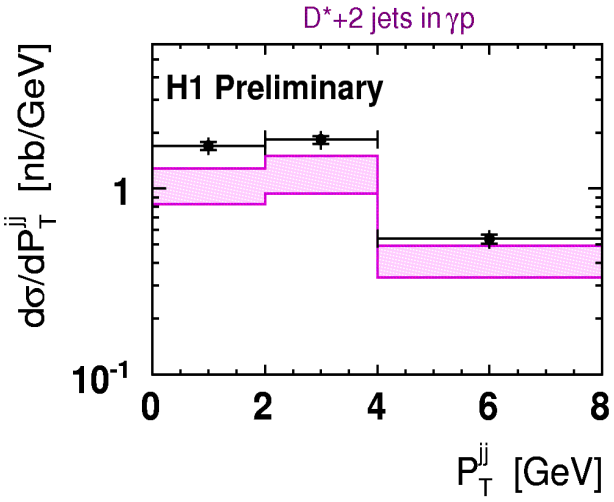
- Events with a D* and 2 jets are required

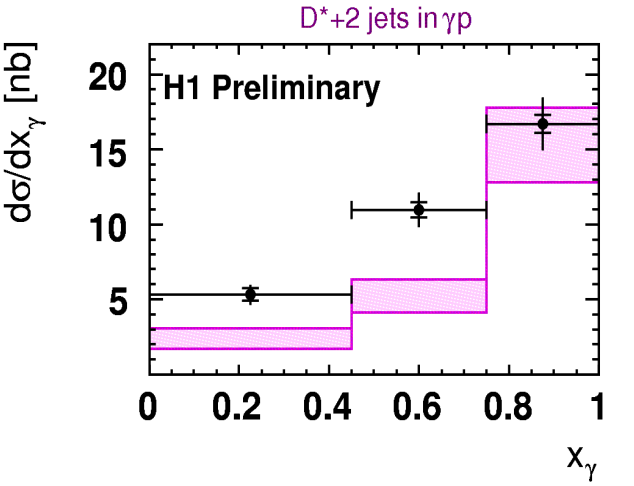






- Asimuthal correlation ΔΦ sensitive to the higher order effects





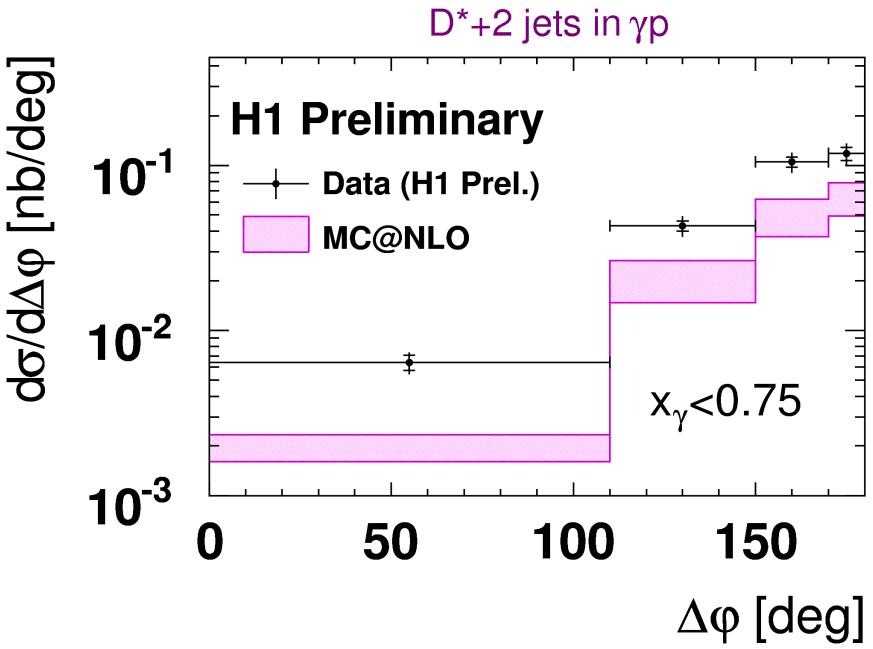
$$x_\gamma^{obs} = \frac{\sum_{Jet_1}(E-p_z) + \sum_{Jet_2}(E-p_z)}{\sum_h (E-p_z)}$$

- in LO, fraction of the photon energy entering hard interaction (direct VS resolved)

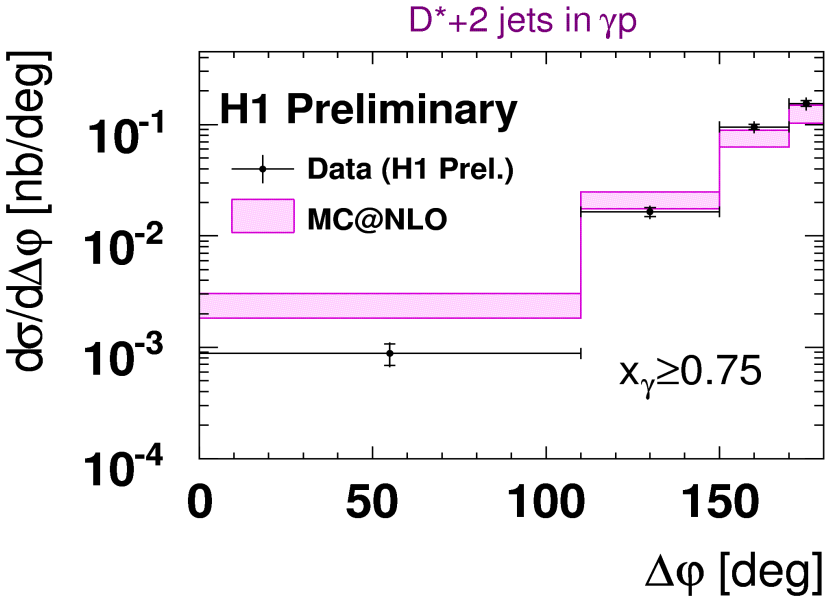
Photoproduction of D* with jets

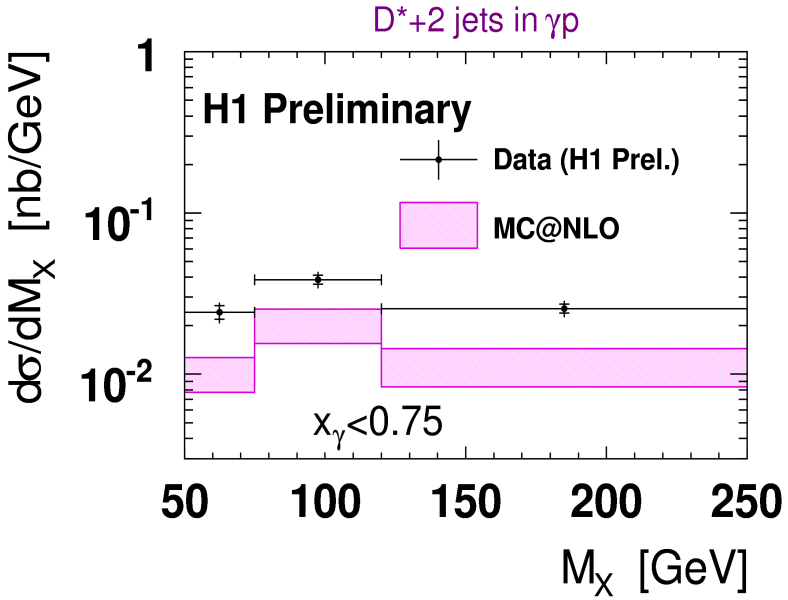
H1prelim-10-072

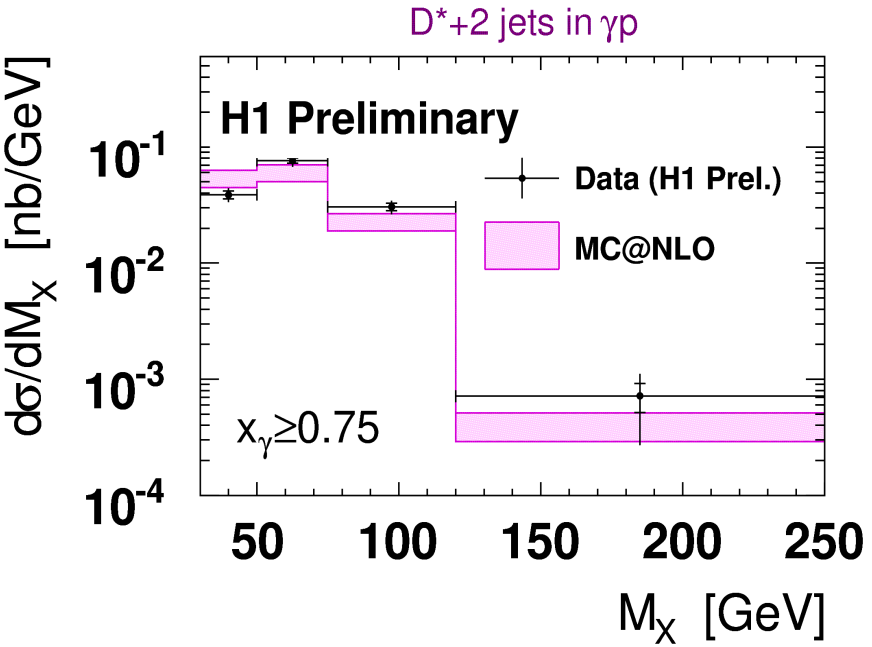
Resolved



Direct







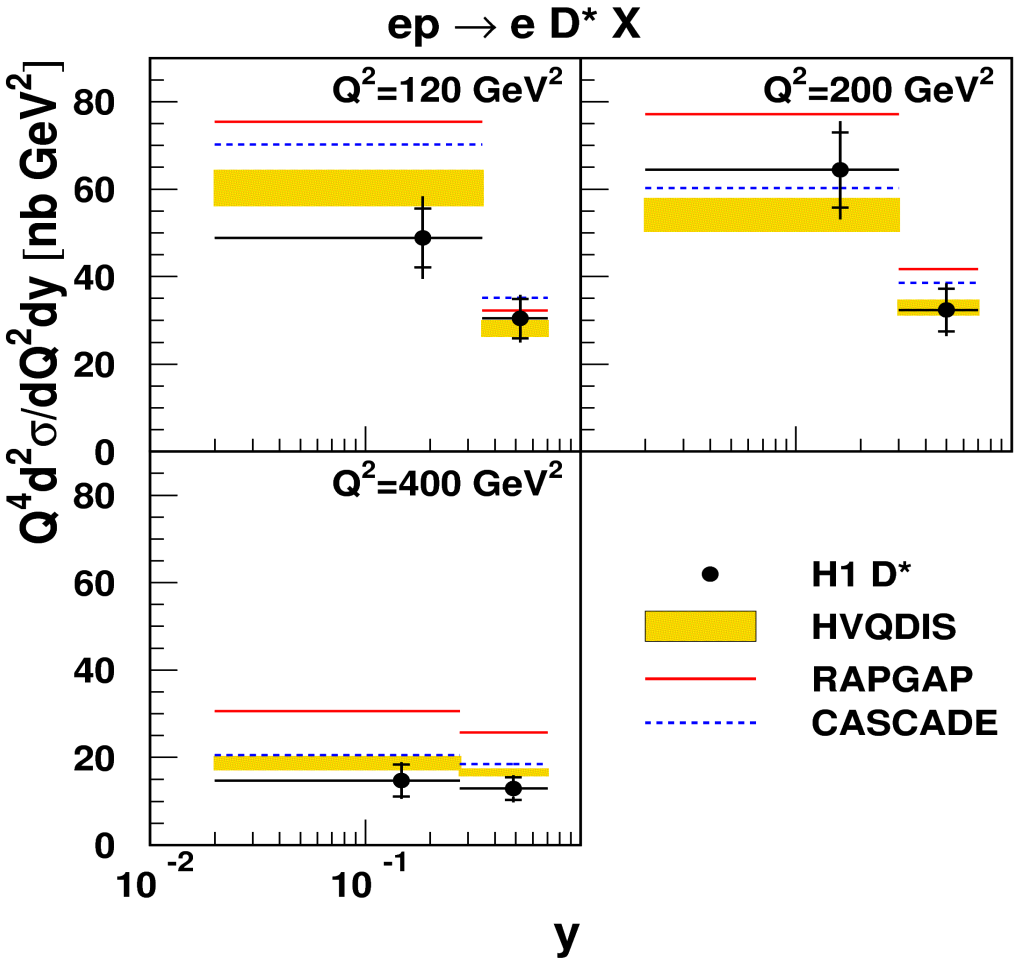
Summary and outlook

- Charm measurements at HERA provide unique test of pQCD, validity of gluon PDFs, multiple scale problem, charm mass
- Wealth of new charm results from ZEUS and H1 are available
- Precision of data is significantly improved with the combination
  - Discrimination among predictions possible
  - Constraints to PDFs
- Further charm results are expected

Thank you very much for your attention!

Backup slides

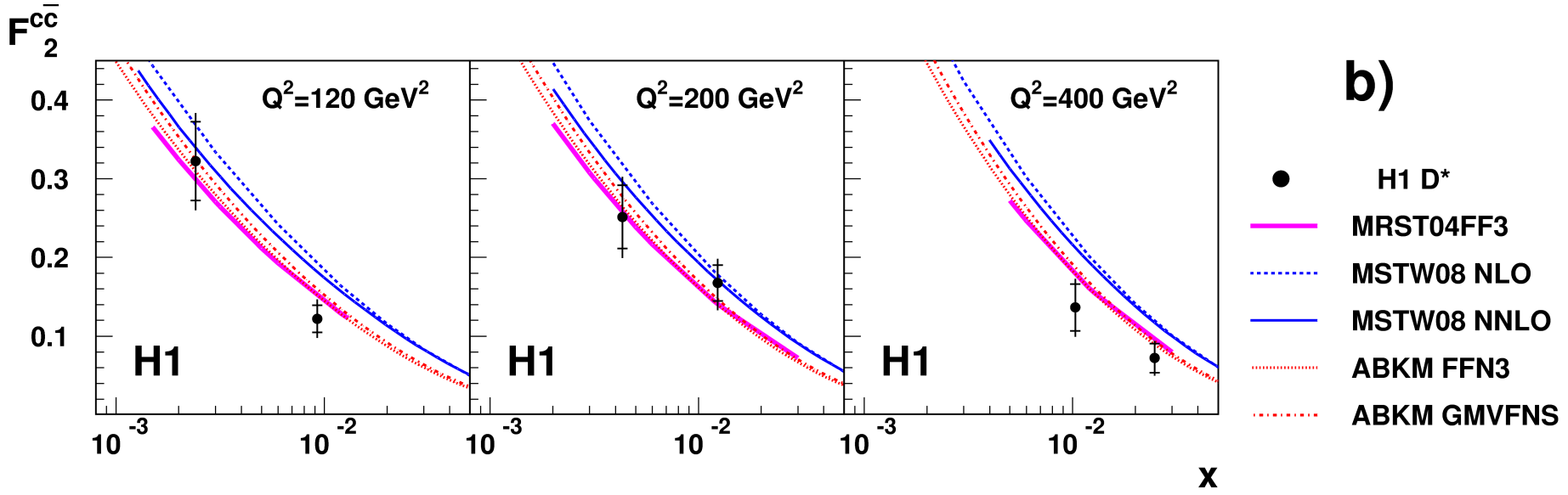
D* measurement in DIS at high Q2



- HVQDIS describes data well
- Monte-Carlo predictions overestimate the data
- These cross-sections are used as an input to F_2^{cc} calculation

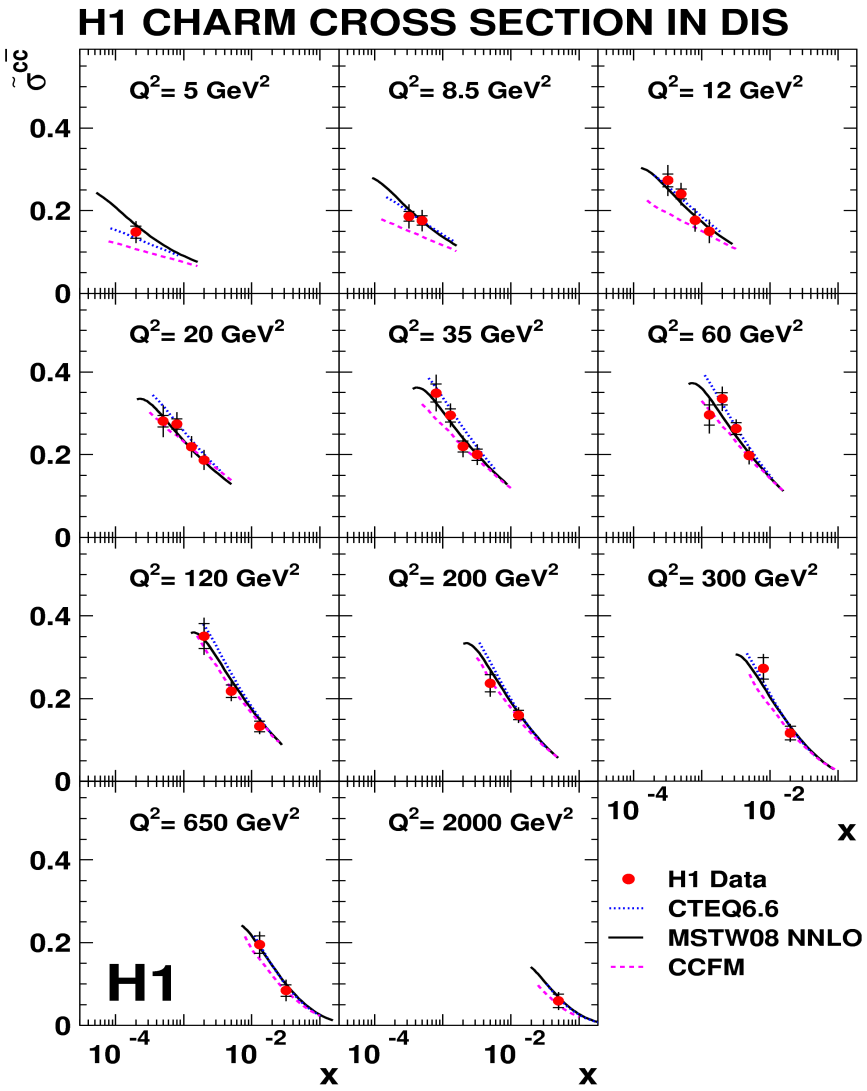
D* measurement in DIS: $F_2^{c\bar{c}}$

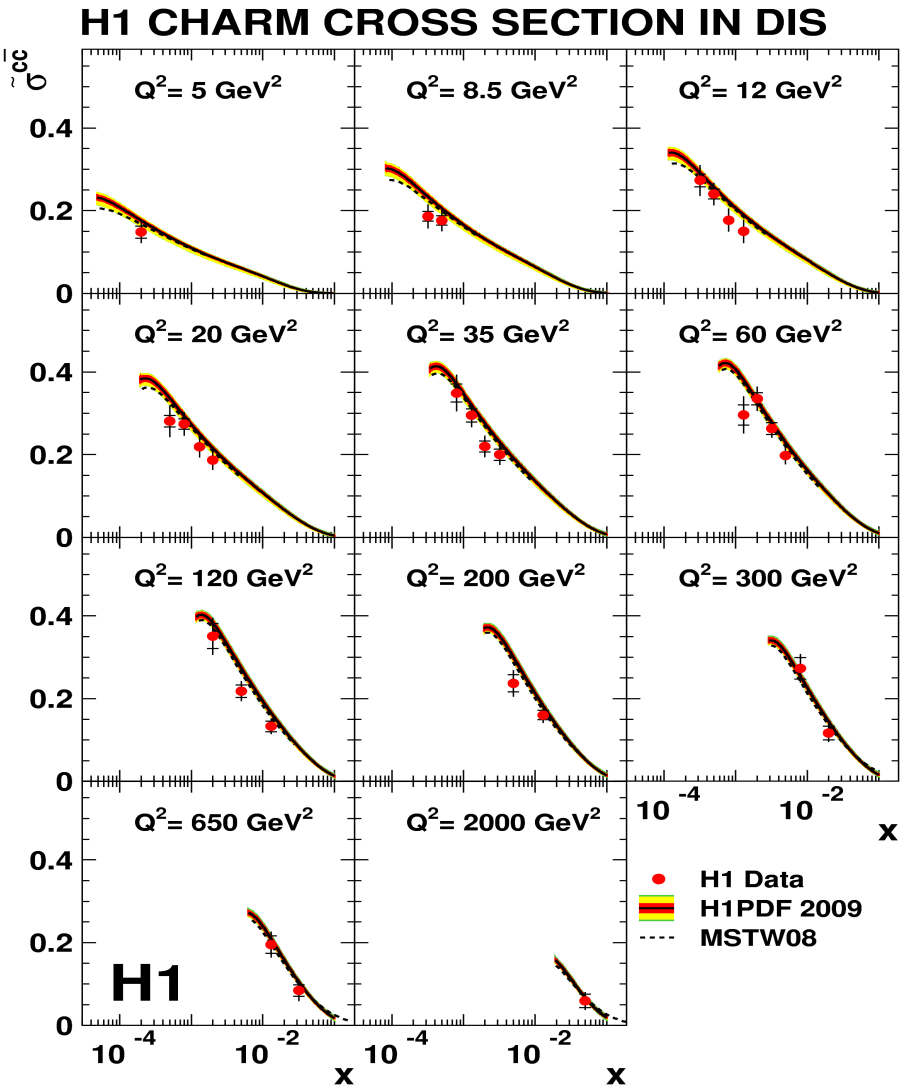
DESY-09-165



- FFNS predictions agree well with data over the full kinematic range considered
- GMVFNS @ NLO – overestimates the data; @ NNLO gives better agreement

Inclusive lifetime measurement



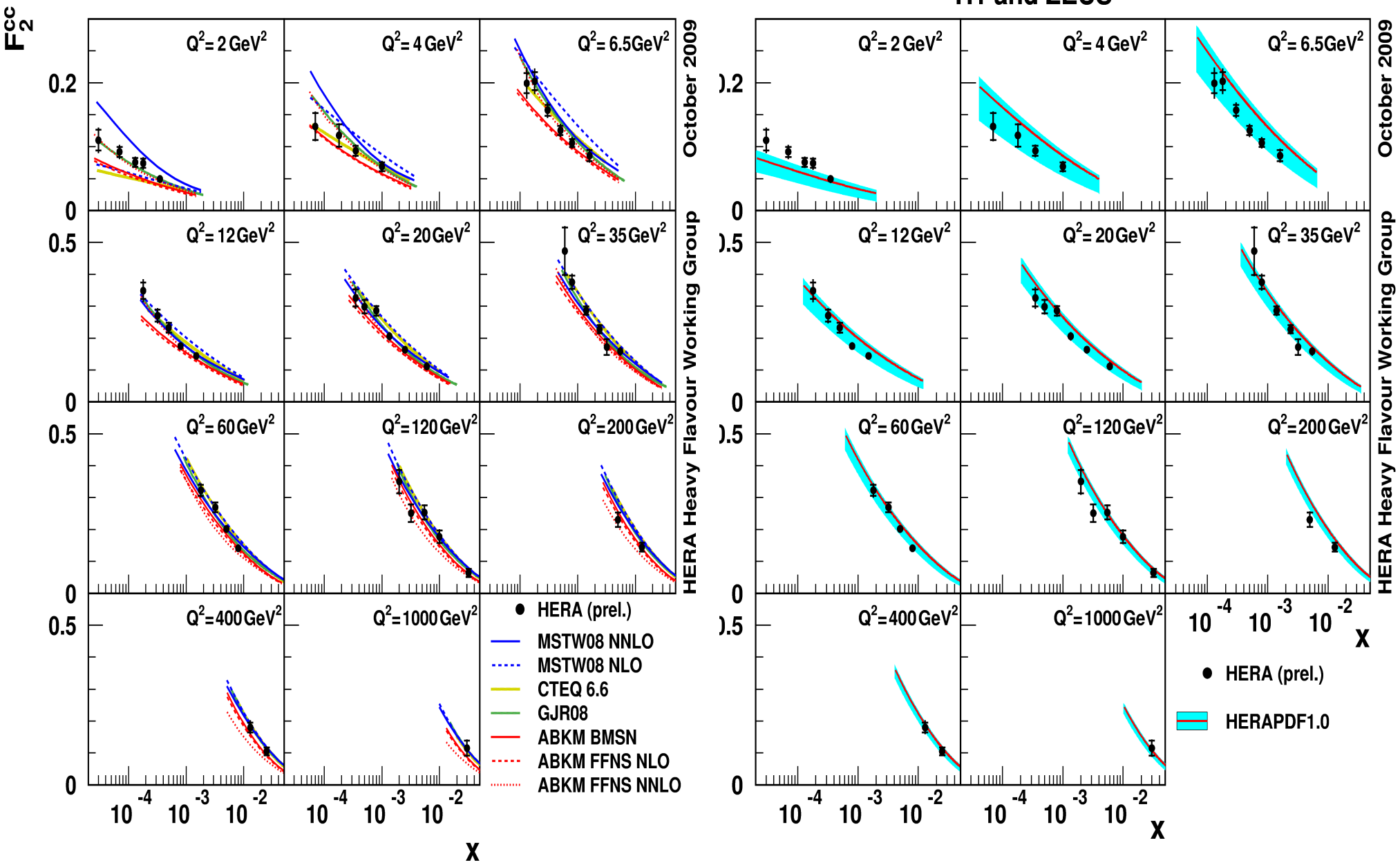


- GM VFNS predictions from CTEQ and MSTW @ NNLO are similar
- CCFM – undershoot the data at the lowest values of Q2 and x
- H1 and MSTW @ NLO – also a reasonable description

H1+ZEUS F_2^{cc} combination

ZEUS-prel-09-015

H1prelim-09-171



- The precision of combined data is smaller than spread between predictions