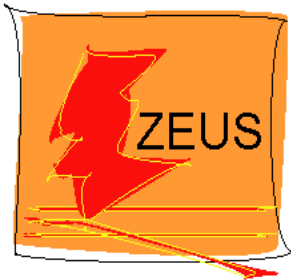




Charm production at HERA

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

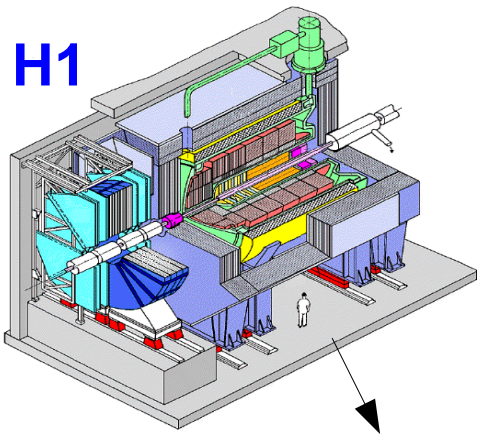


Outline

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

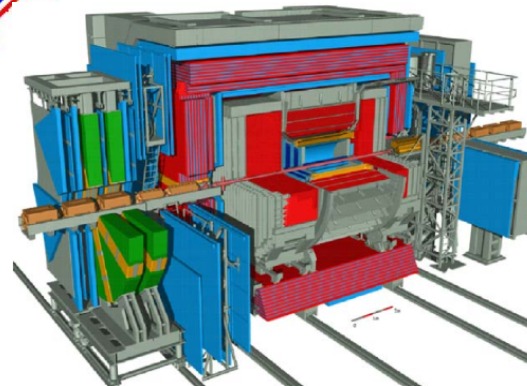
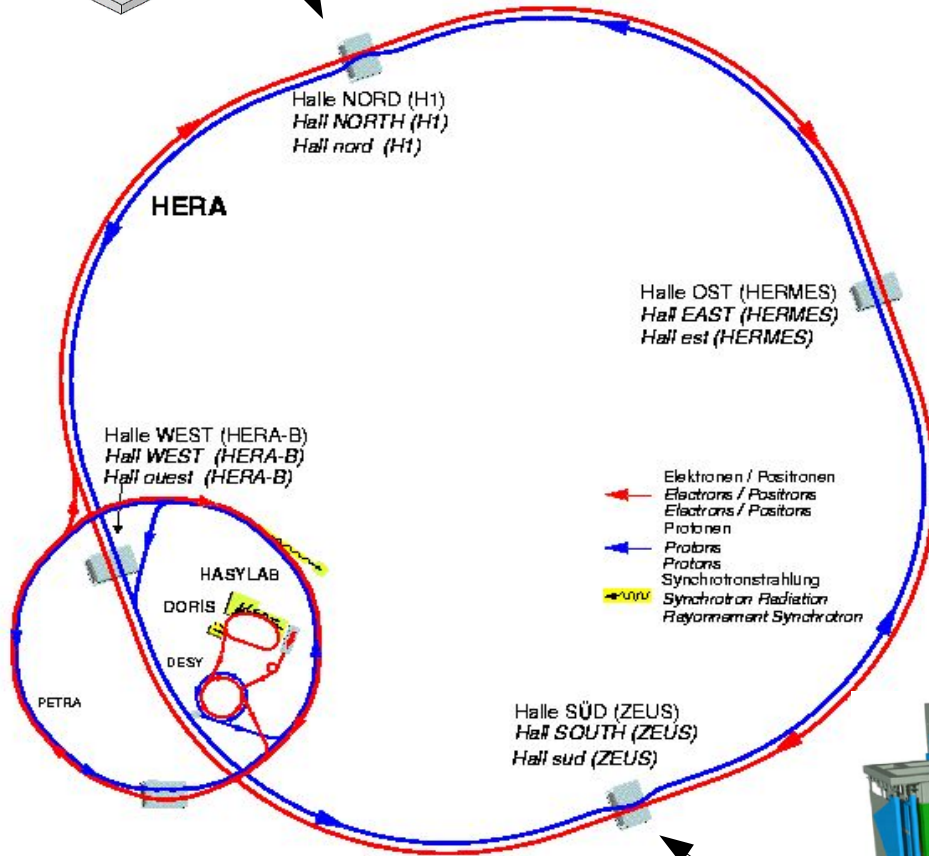


H1



HERA collider

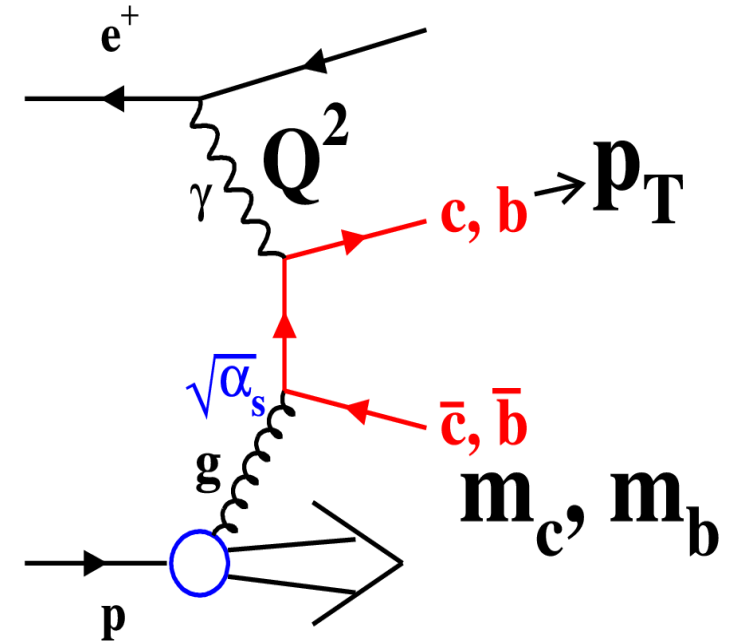
- Protons 920 GeV
 - Electrons 27.6 GeV
- $$\left. \begin{array}{l} \text{Protons } 920 \text{ GeV} \\ \text{Electrons } 27.6 \text{ GeV} \end{array} \right\} \sqrt{s} = 318 \text{ GeV}$$
- Operational: 1992-2007
 - H1 and ZEUS – general purpose hermetic detectors
 - ~500 pb⁻¹ per experiment accumulated 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:

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

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

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

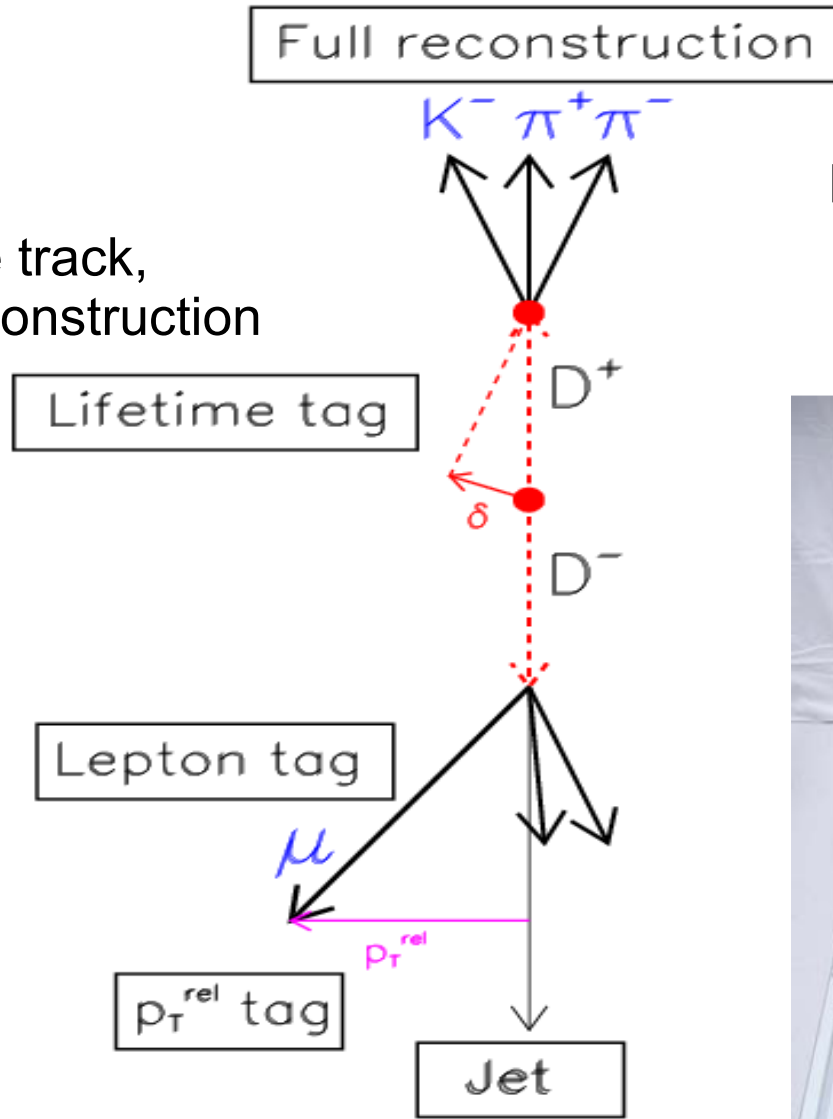
- NLO QCD calculations
 - Massive scheme (FFNS): HVQDIS, FMNR
 - Massless scheme (ZMVFNS)
 - Mixed schemes (GMVFNS)
- NNLO partially available

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

Charm tagging methods

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

Impact parameter of the track,
secondary vertex reconstruction



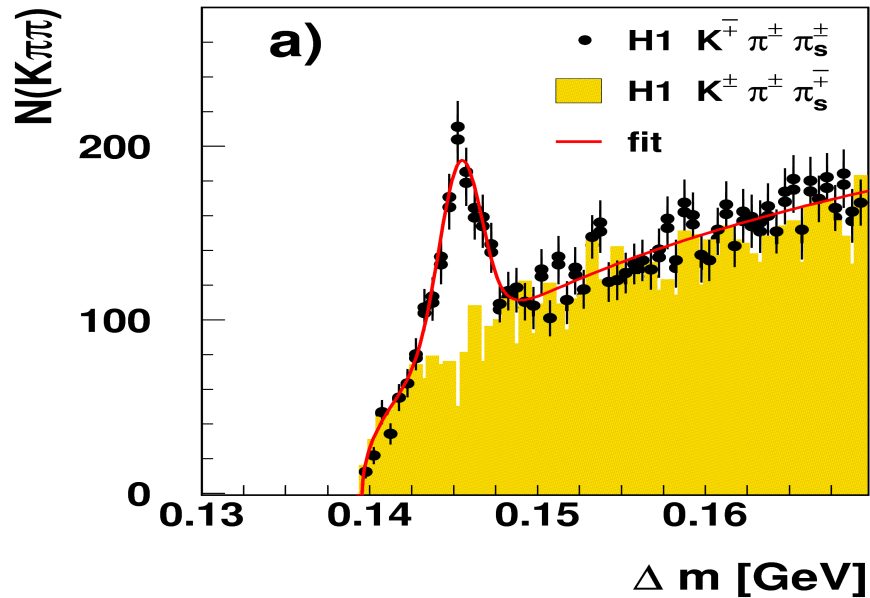
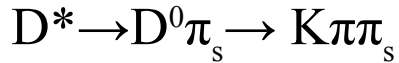
High resolution vertex detectors are crucial for lifetime tagging



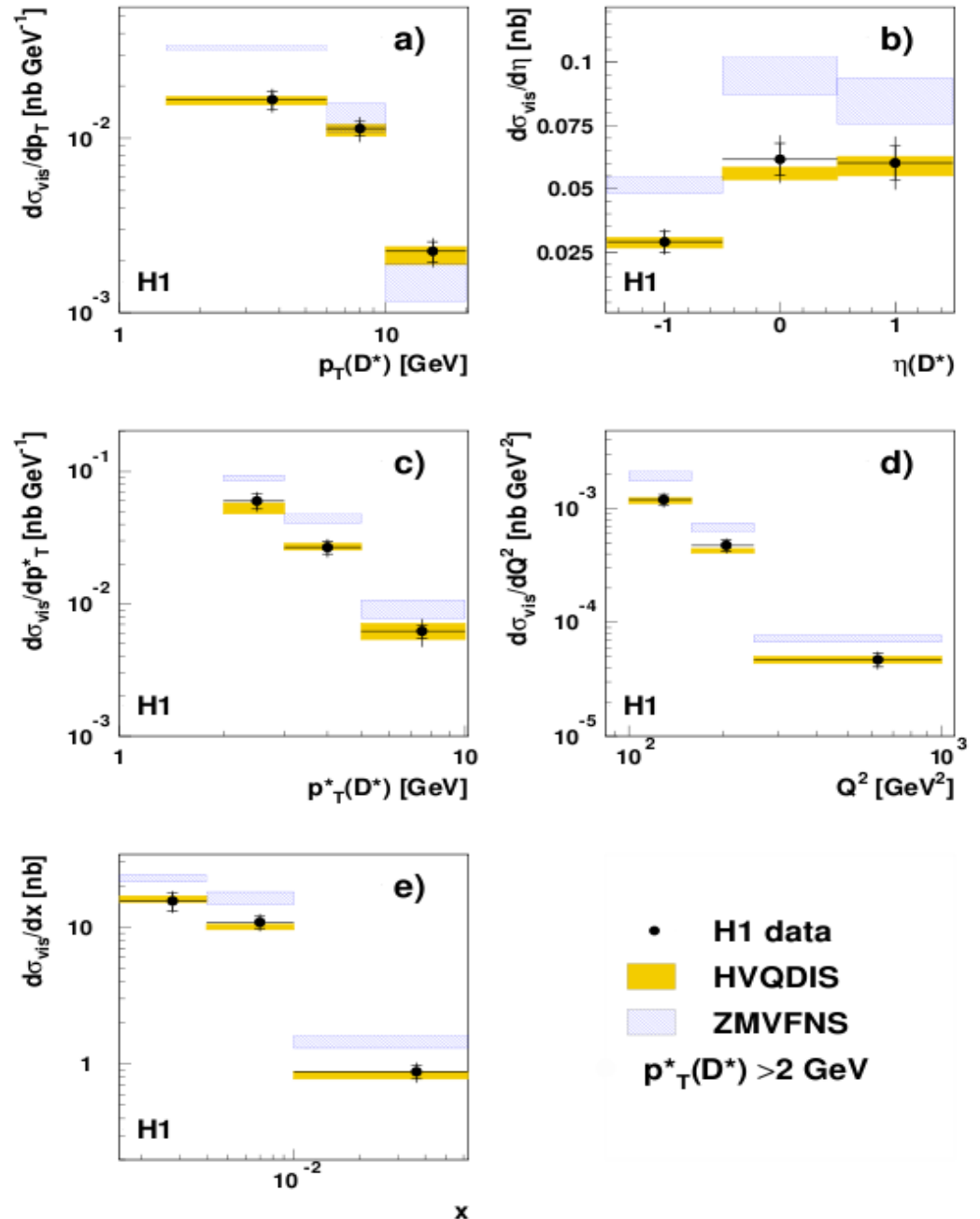
- Methods can be combined
- Can be used for *single or double* tagging

D* measurement in DIS at high Q²

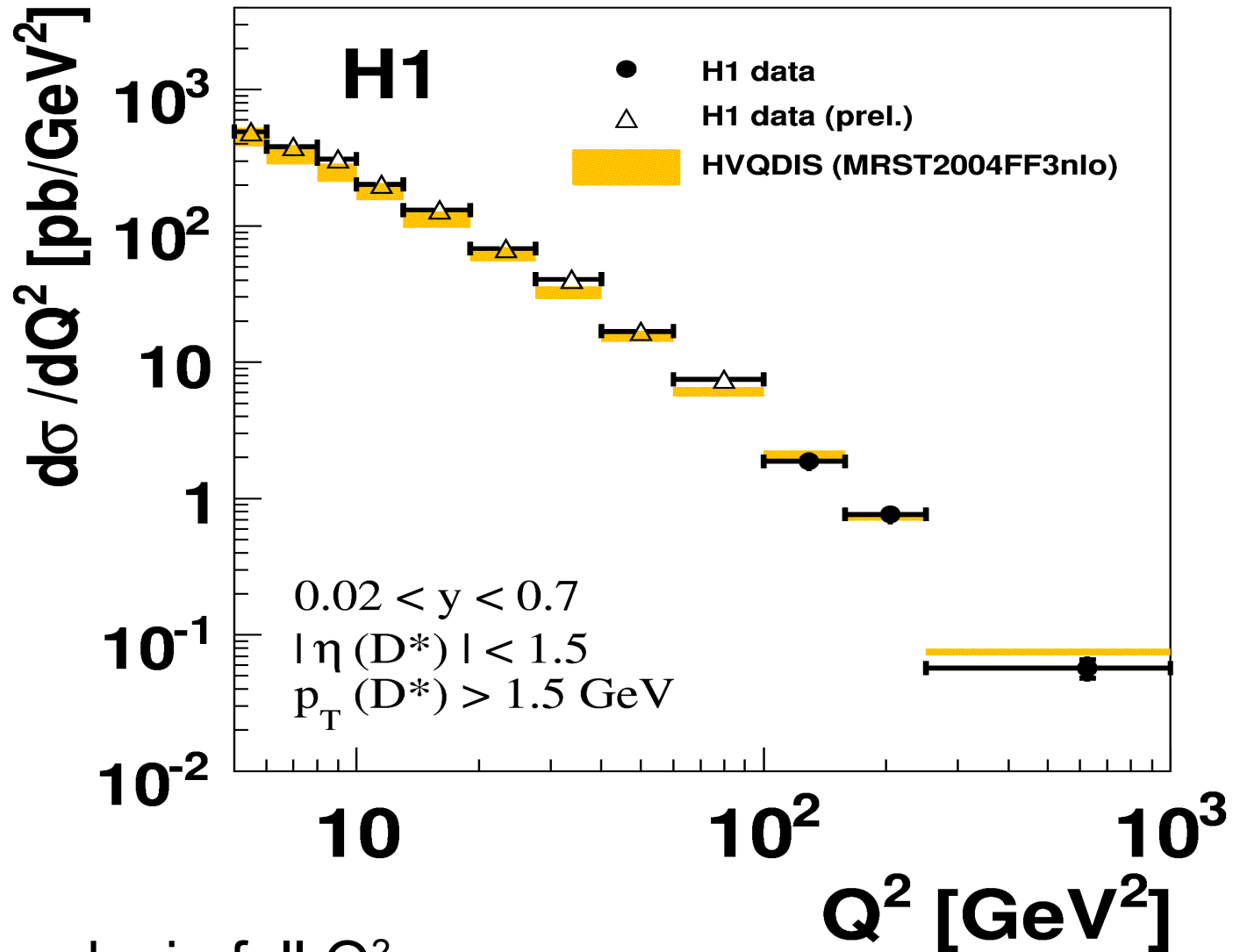
- 100 < Q² < 1000 GeV²
- “Golden” decay channel:



- HVQDIS describes data well
- ZMVFNS fails to describe data even at high Q² (not only in normalization but also in shape)



D* production in DIS



- HVQDIS works in full Q^2 range

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

H1prelim08-72

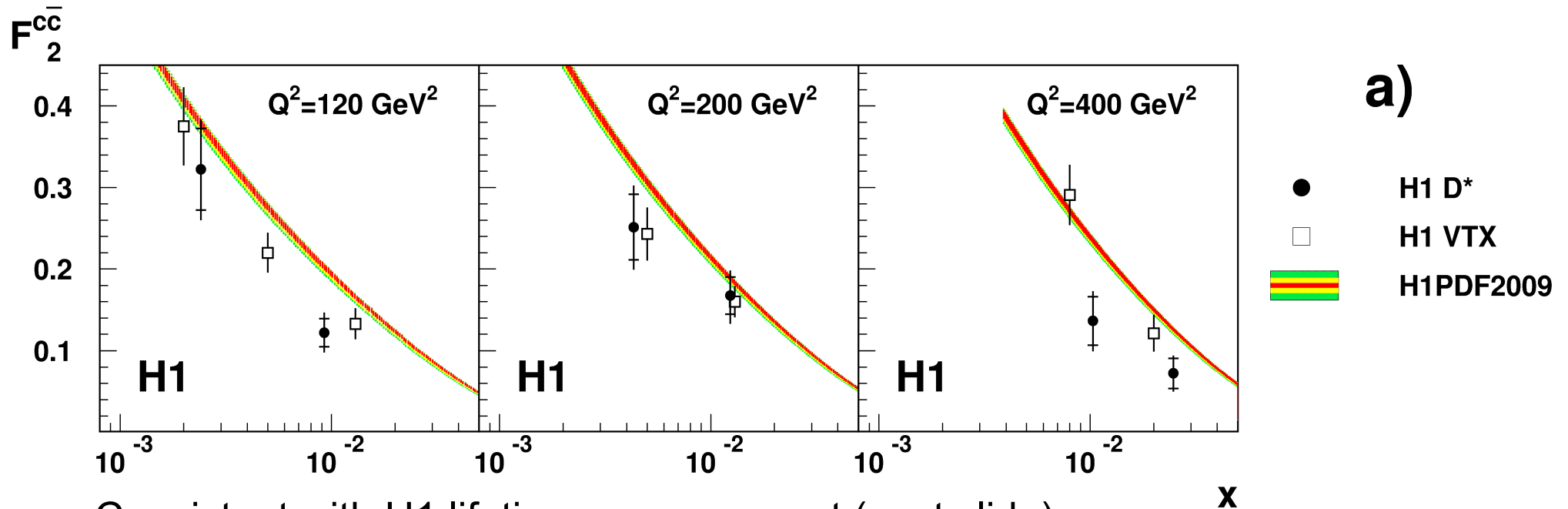
D* measurement in DIS at high Q²: F₂^{cc̄}

- Charm structure function (neglecting F_L)

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

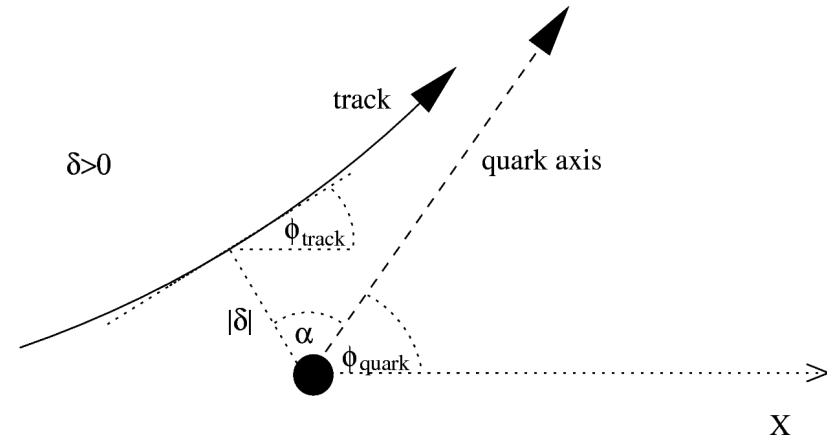
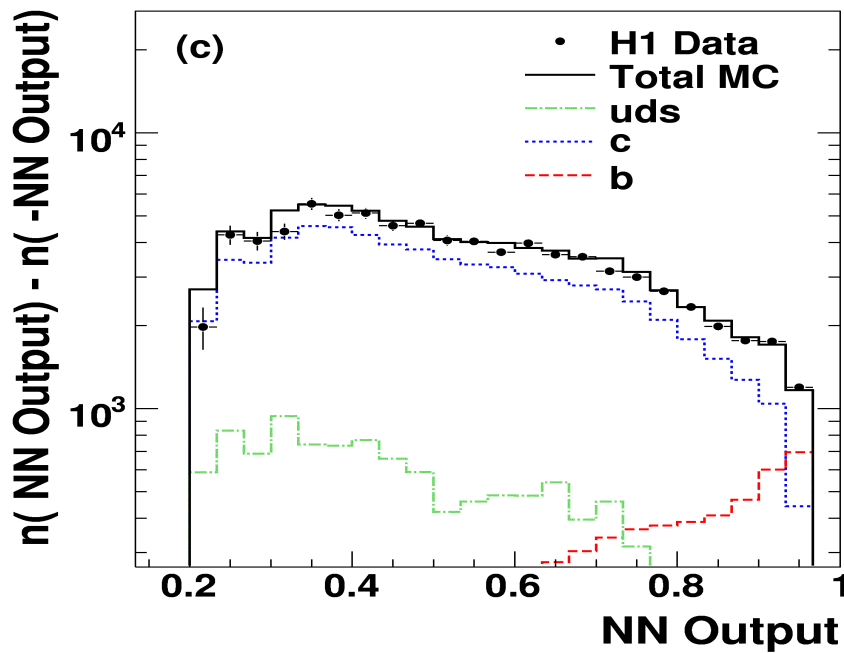
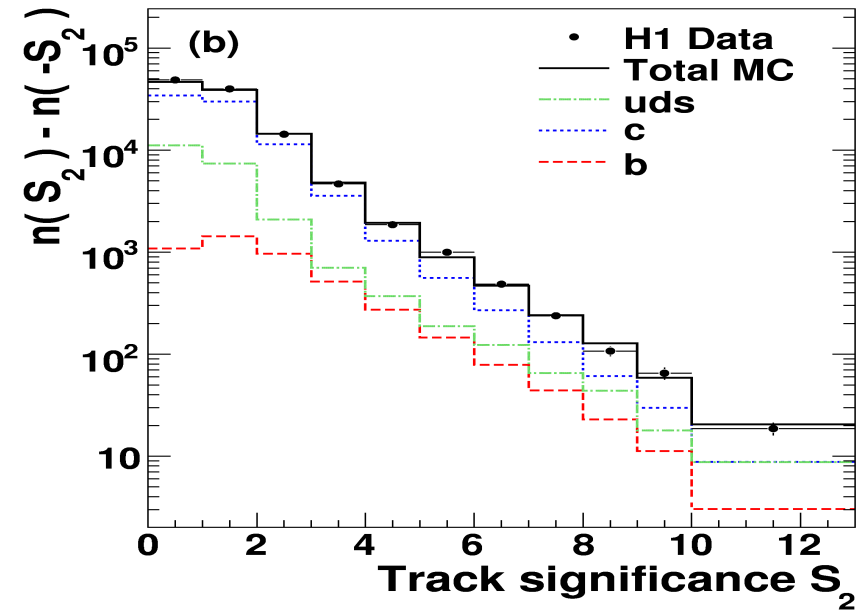
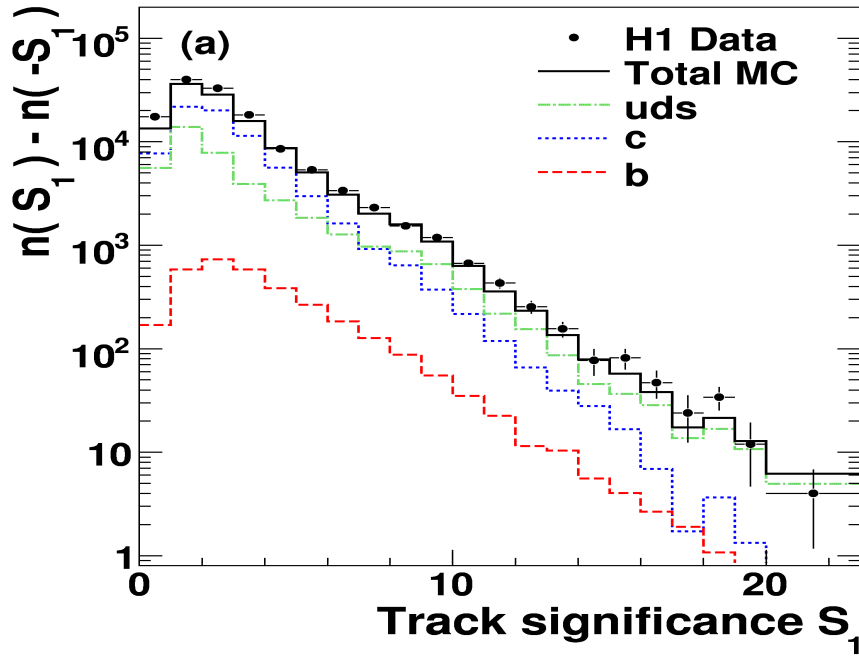
- NLO QCD to extrapolate to full phase space:

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



- Consistent with H1 lifetime measurement (next slide)

Inclusive lifetime measurement: method

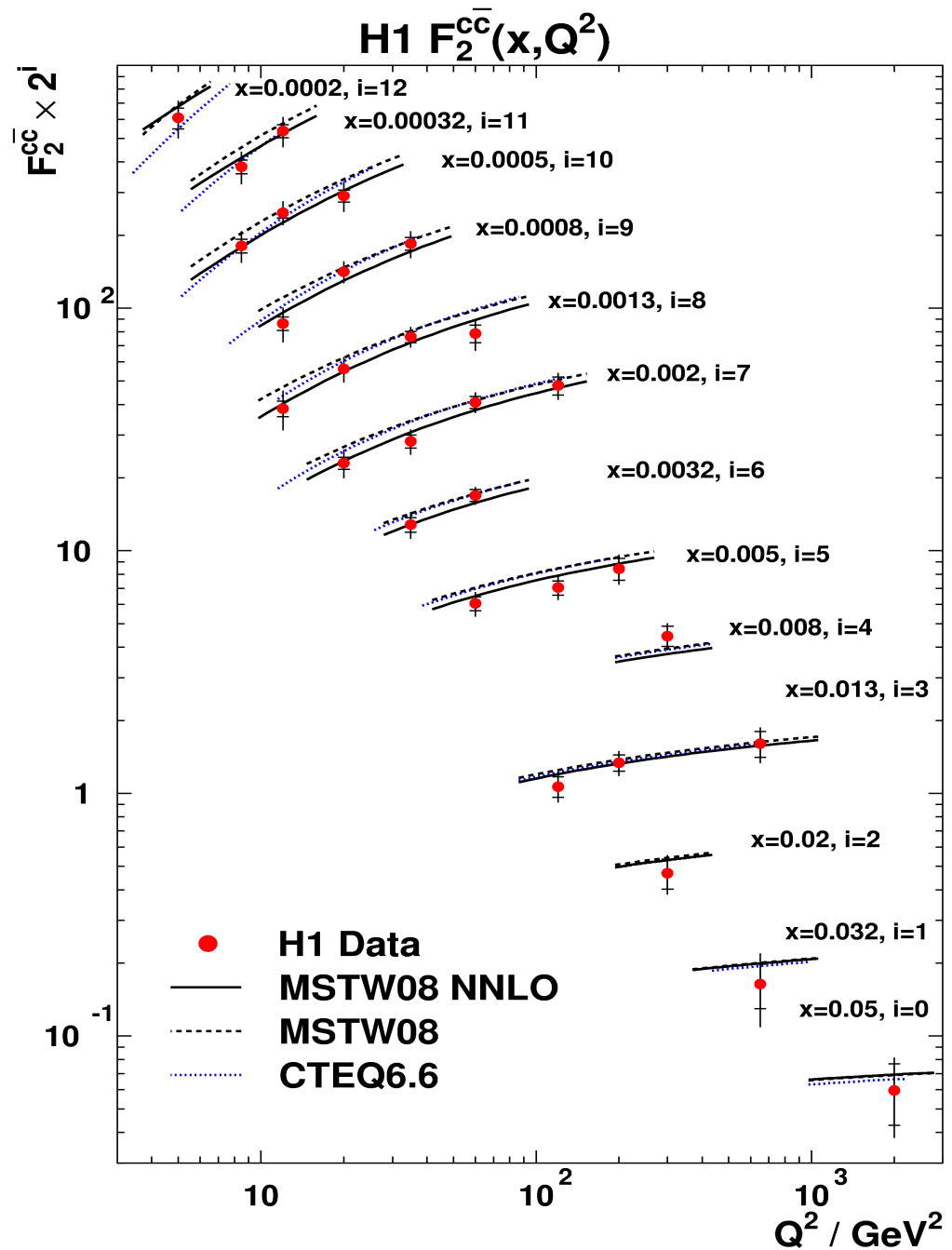


S_1 , S_2 and NN are fitted simultaneously

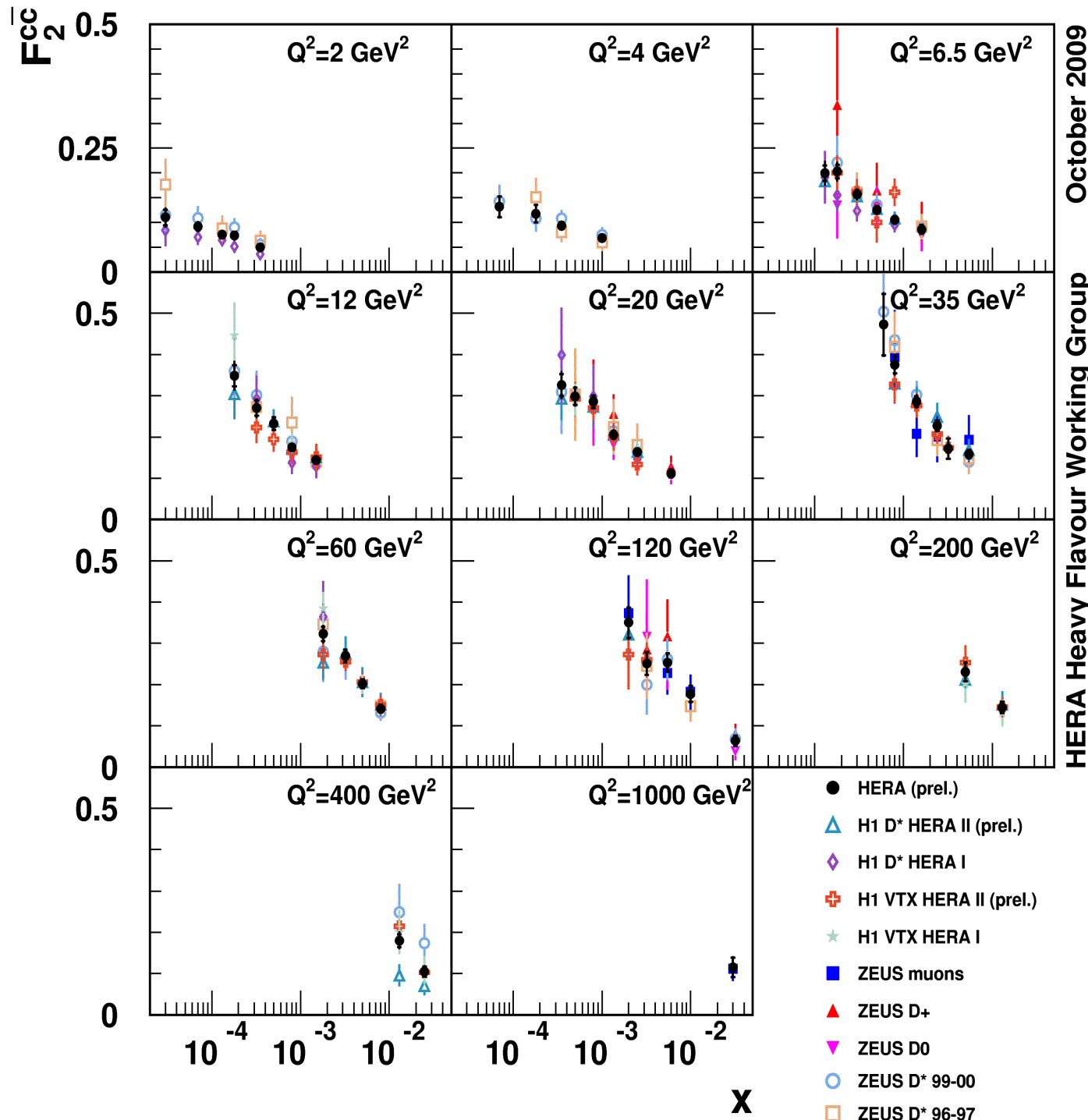
- Results on beauty – talk by Michel Sauter

Inclusive lifetime measurement: F_2^{cc}

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



H1+ZEUS F_2^{cc} combination



ZEUS-prel-09-015

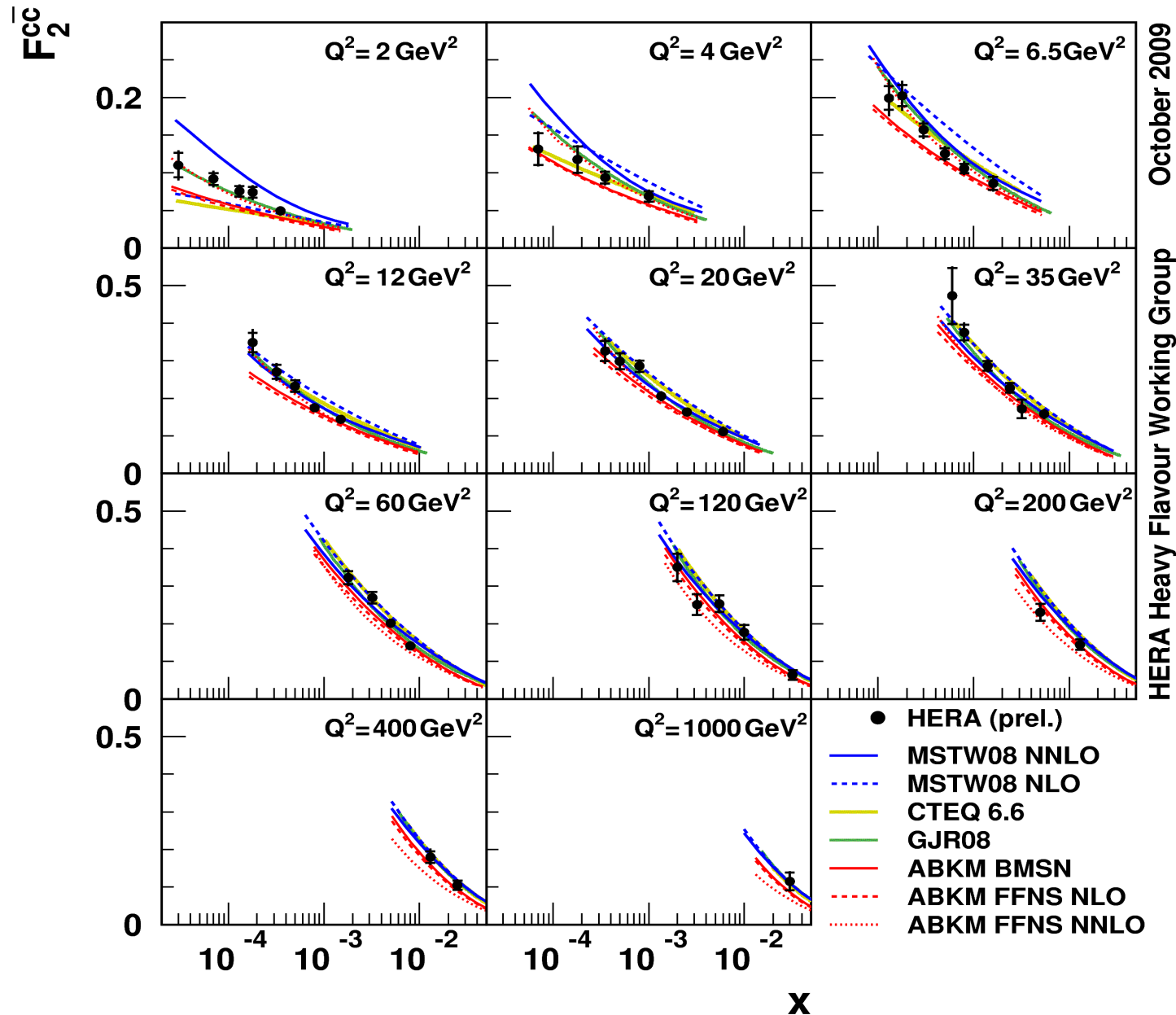
H1prelim-09-171

- 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



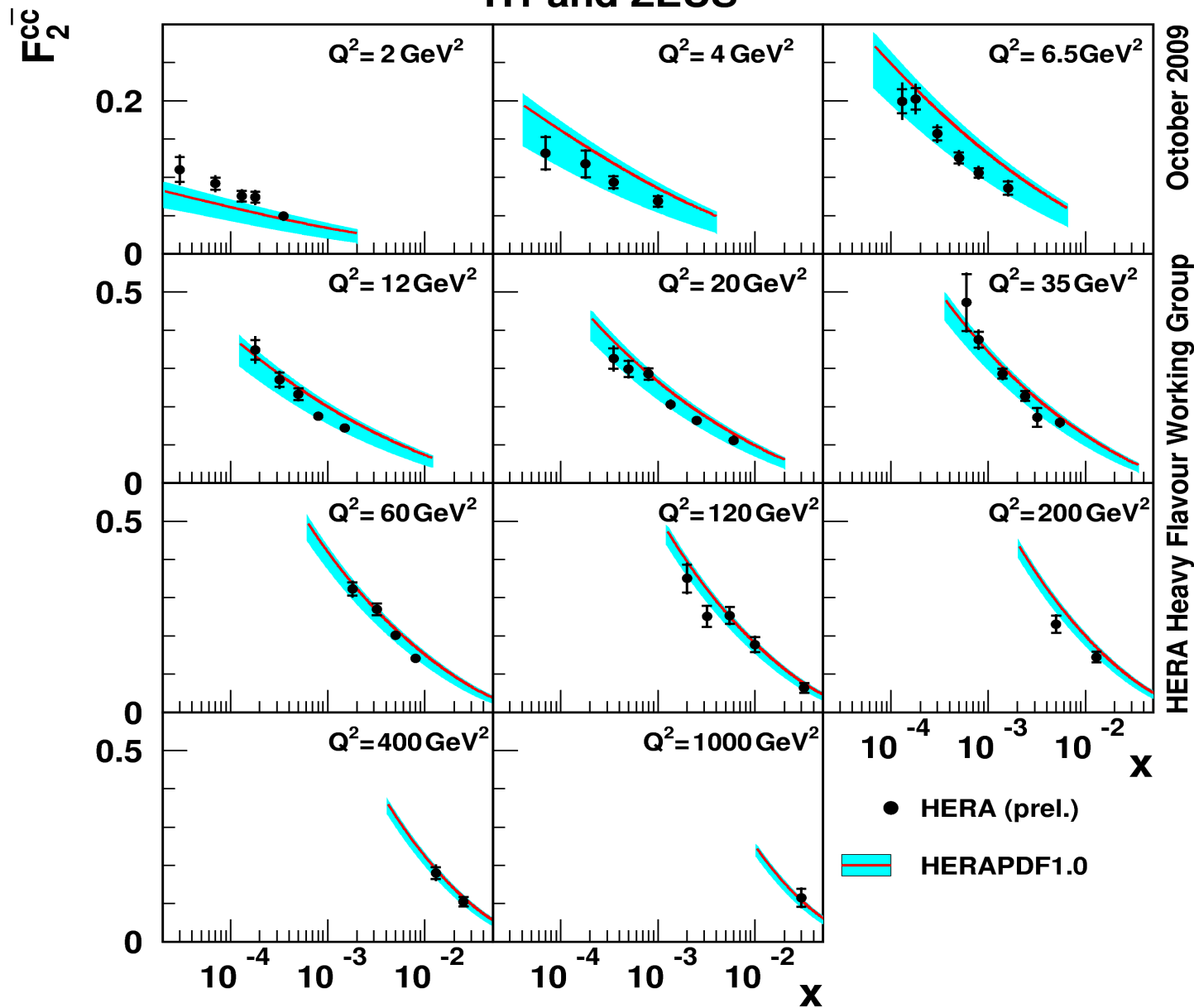
- The precision of combined data is smaller than spread between predictions

H1+ZEUS F_2^{CC} combination

ZEUS-prel-09-015

H1prelim-09-171

H1 and ZEUS



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

Measurement of D^+ in DIS

ZEUS-prel-10-005

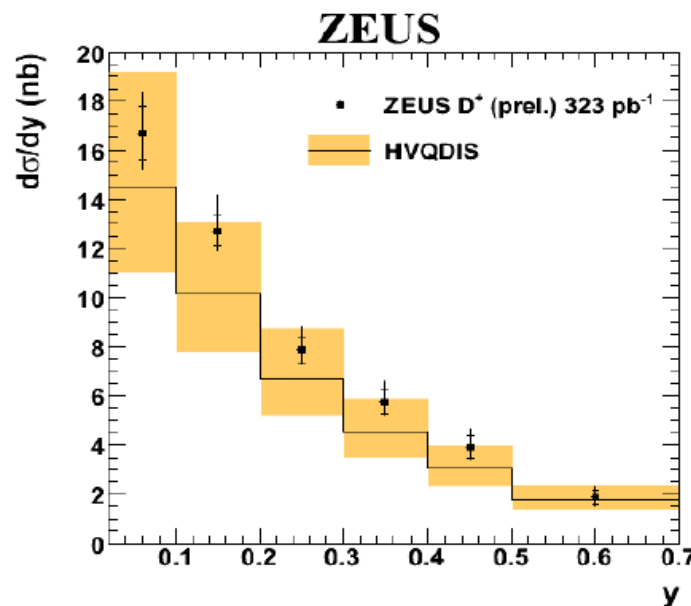
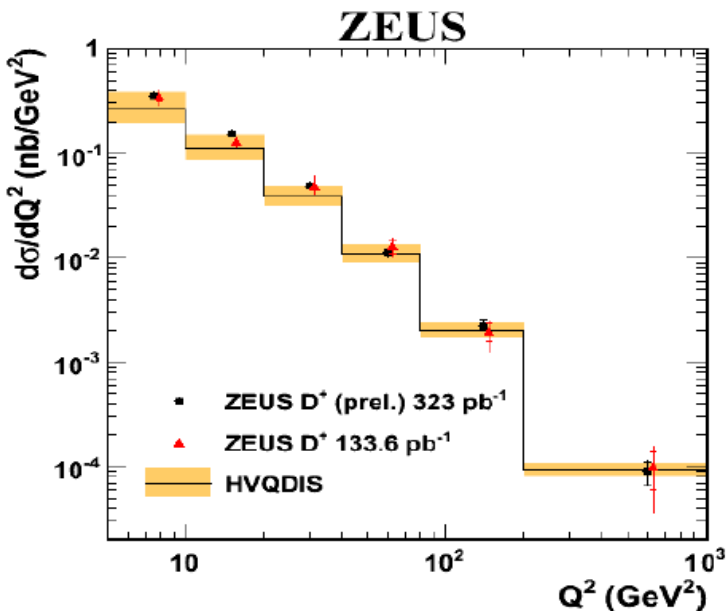
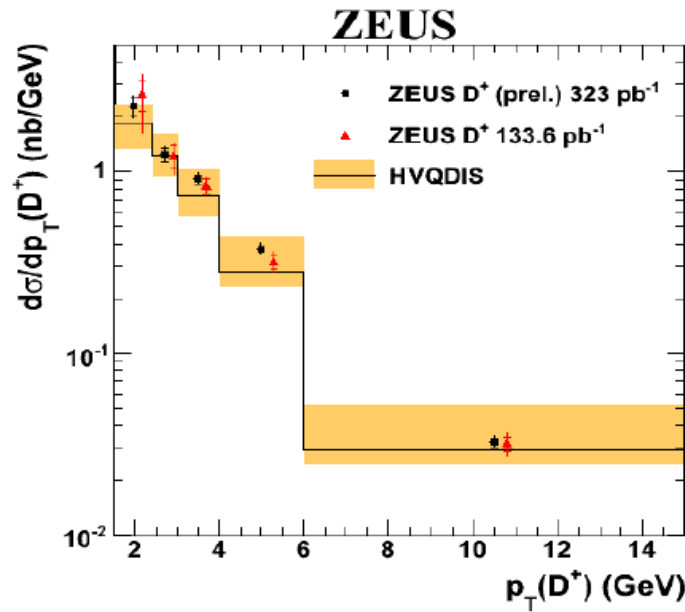
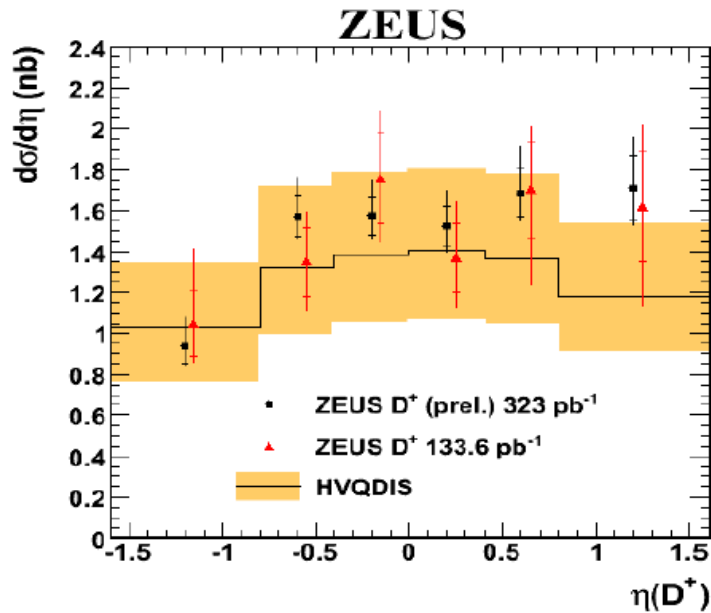
- $D^+ \rightarrow K^- \pi^+ \pi^+$ decay channel is used
- Decay vertex is fully reconstructed

- Kinematic region:
 $5 < Q^2 < 1000 \text{ GeV}^2$
 $0.02 < y < 0.7$
 $1.5 < p_T(D^+) < 15 \text{ GeV}$
 $|\ln(D^+)| < 1.6$

- Much larger statistics \rightarrow precision improved

- Data consistent with previous ZEUS results

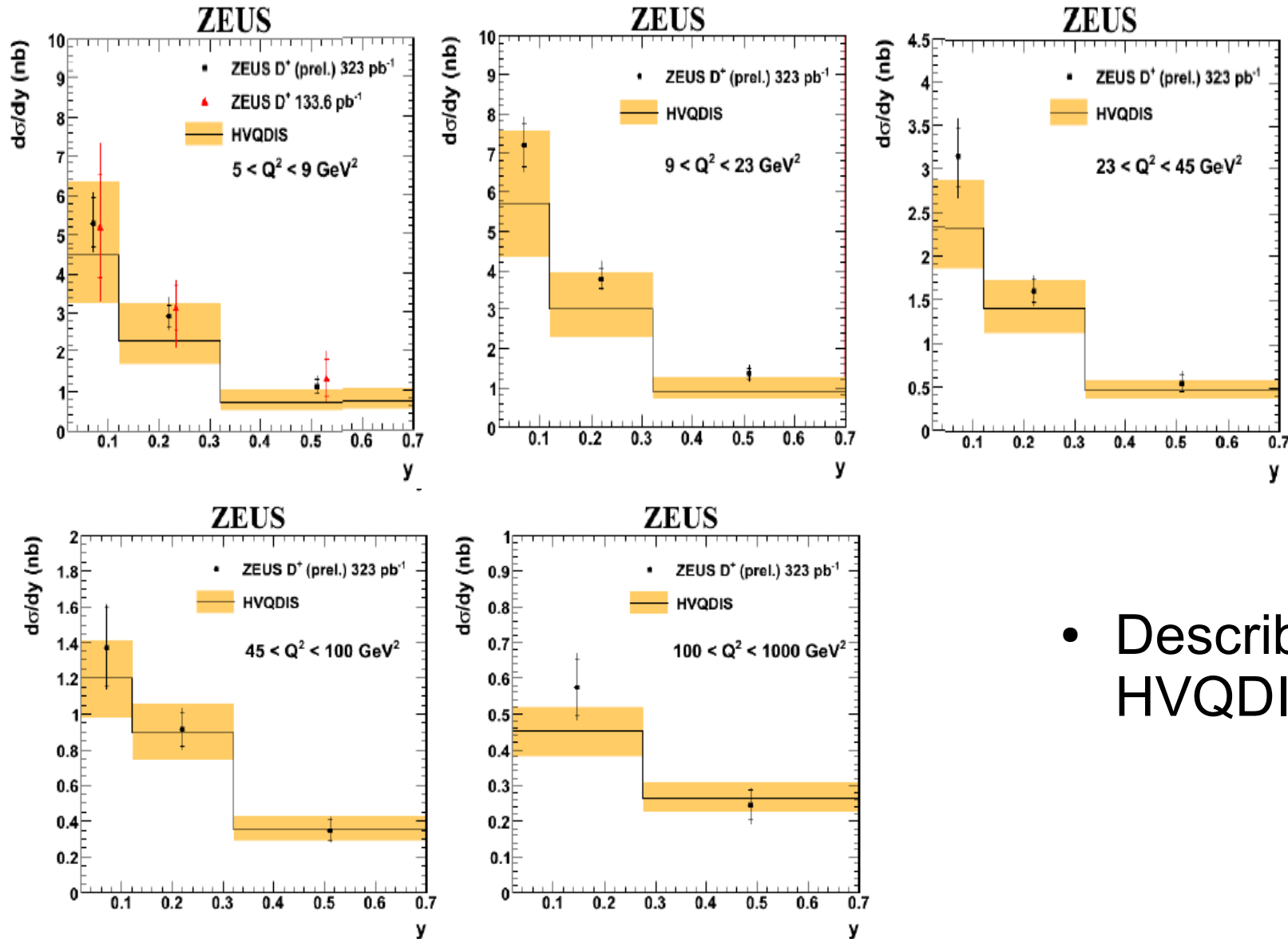
- Good description by HVQDIS



Measurement of D^+ in DIS

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

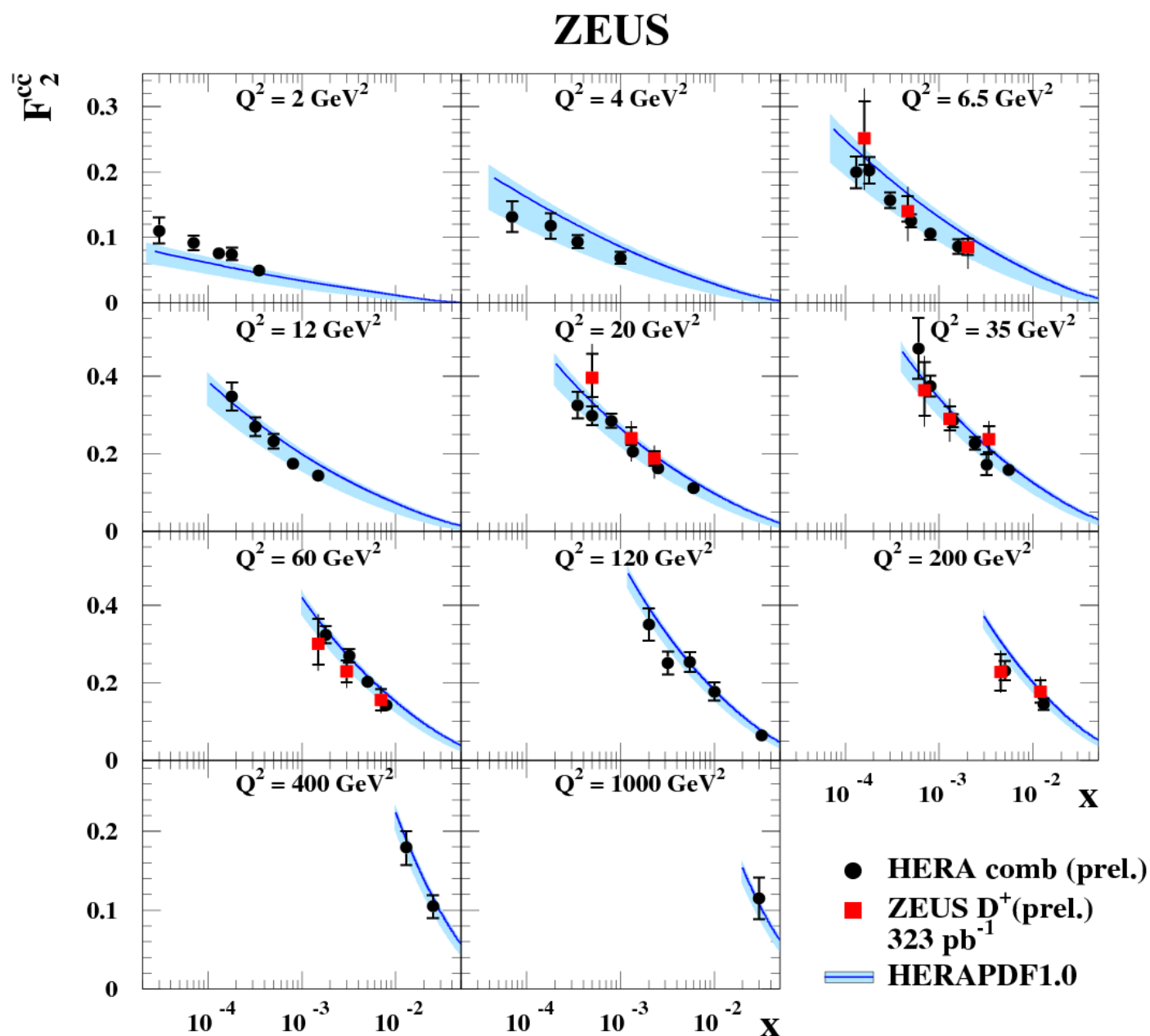
ZEUS-prel-10-005



- Described well by HVQDIS

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

ZEUS-prel-10-005

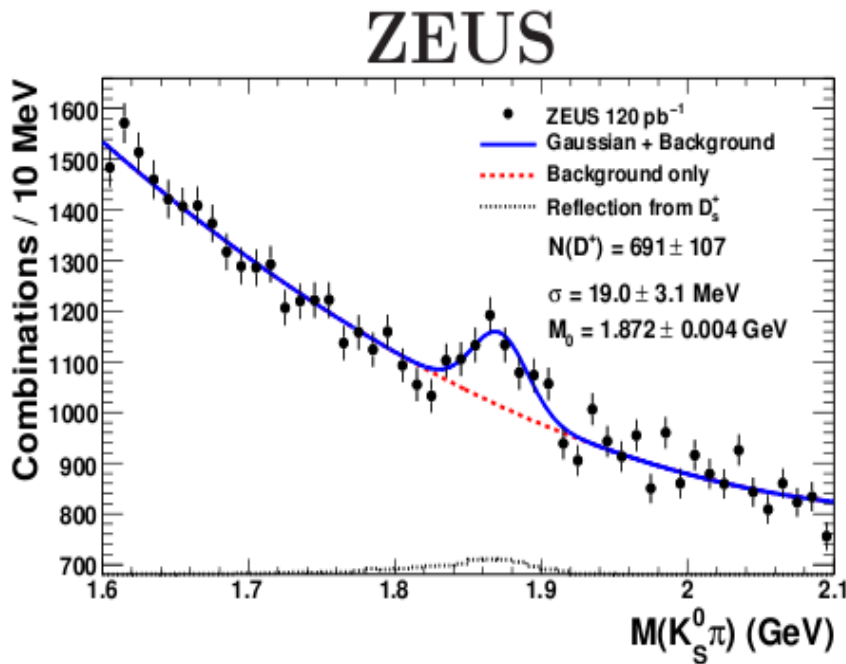


- New data are consistent with HERA combined results
- Will be used in the future for the combination

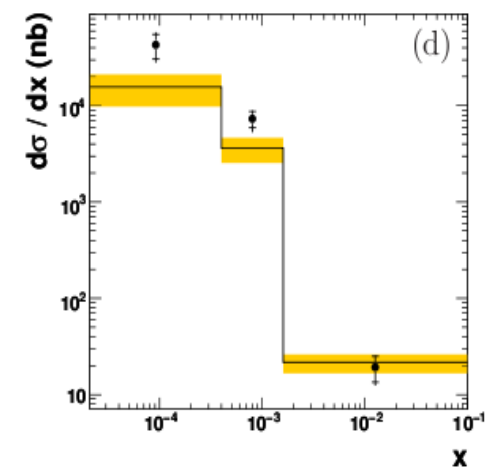
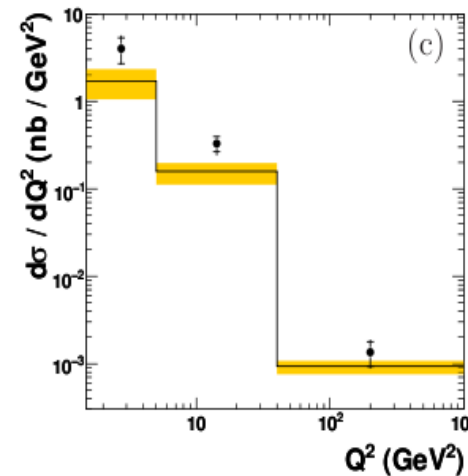
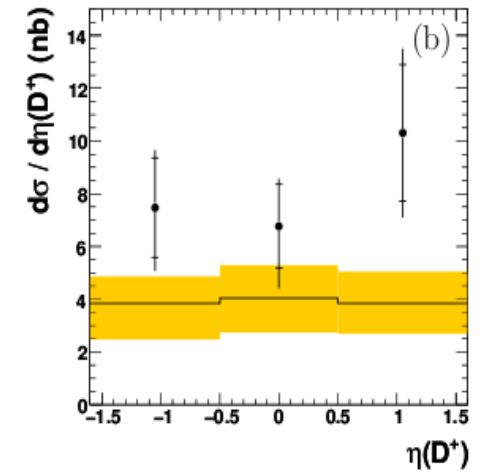
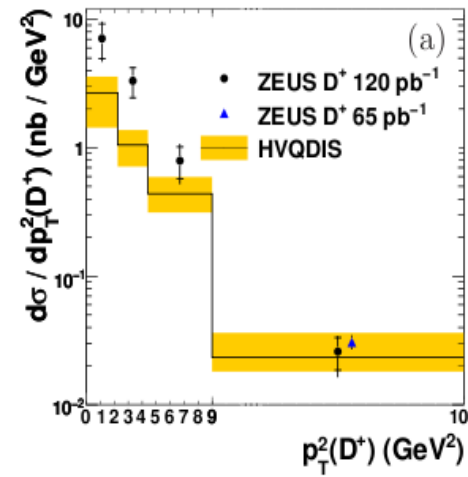
Measurement of D^+ and Λ_c^+ production in DIS

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

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



ZEUS

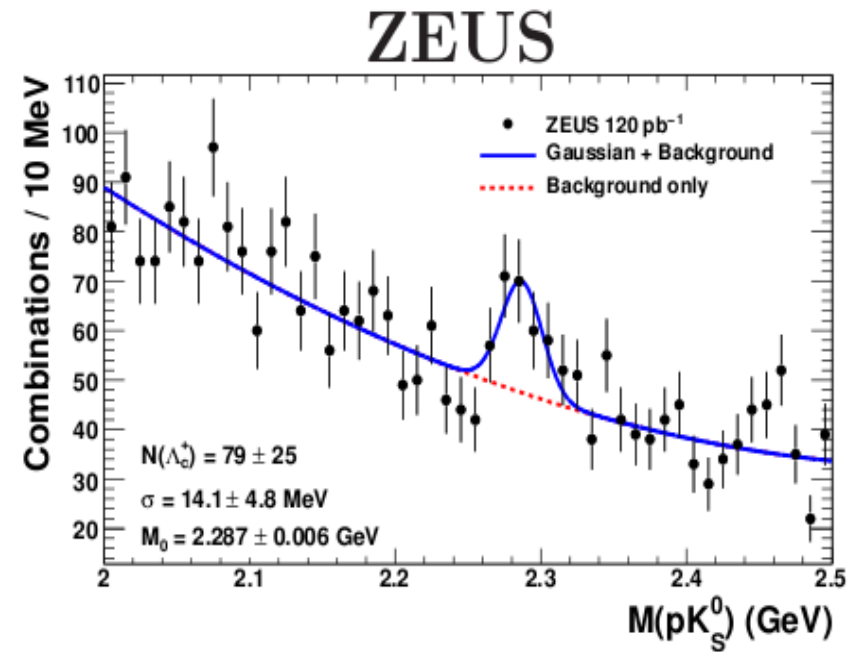
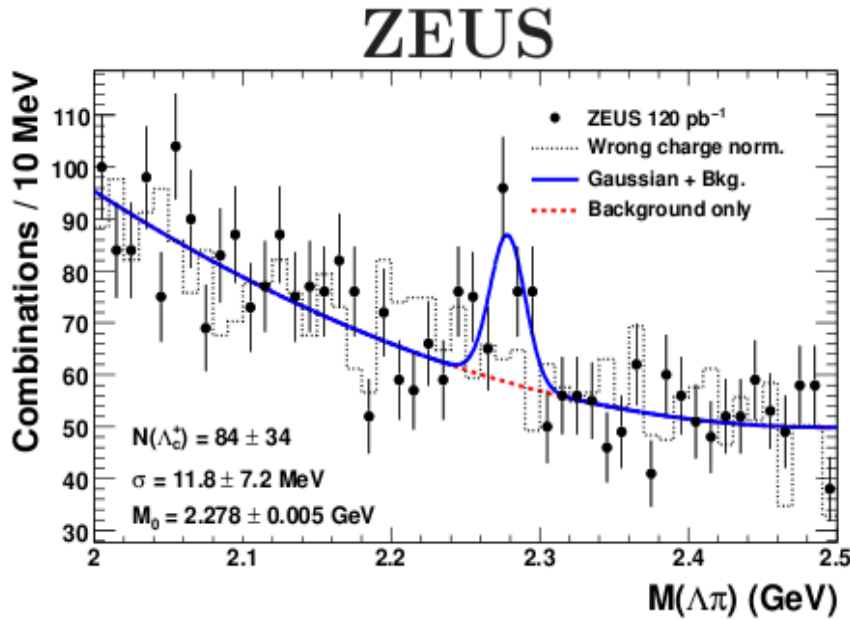


- Measured phase space extended to lower p_T
- Cross-sections described reasonably by HVQDIS

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



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

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

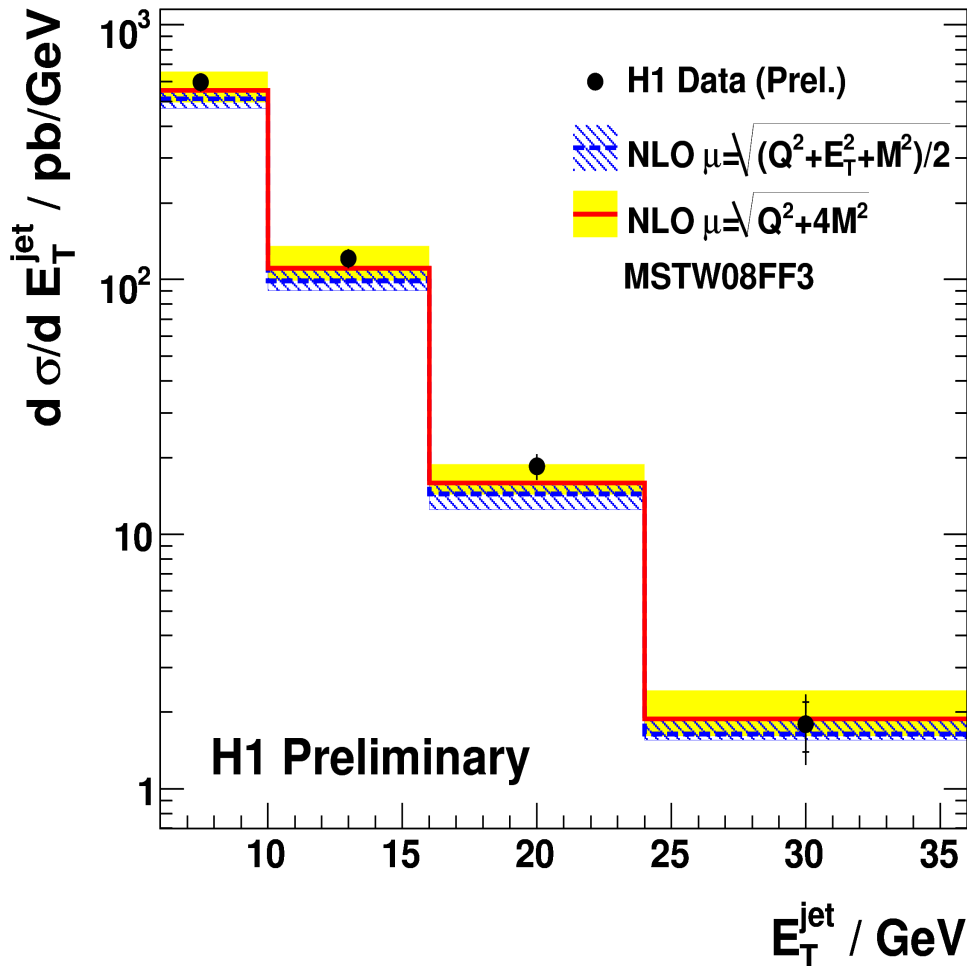
	$f(c \rightarrow \Lambda_c^+)$
ZEUS (DIS)	$0.117 \pm 0.033 \text{ (stat.) } {}^{+0.026}_{-0.022} \text{ (syst.) } \pm 0.027 \text{ (br.)}$
ZEUS (γp) [9]	$0.144 \pm 0.022 \text{ (stat.) } {}^{+0.013}_{-0.022} \text{ (syst.) } {}^{+0.037}_{-0.025} \text{ (br.)}$
combined e^+e^- data	$0.076 \pm 0.007 \text{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

Measurement of Charm Jets in DIS

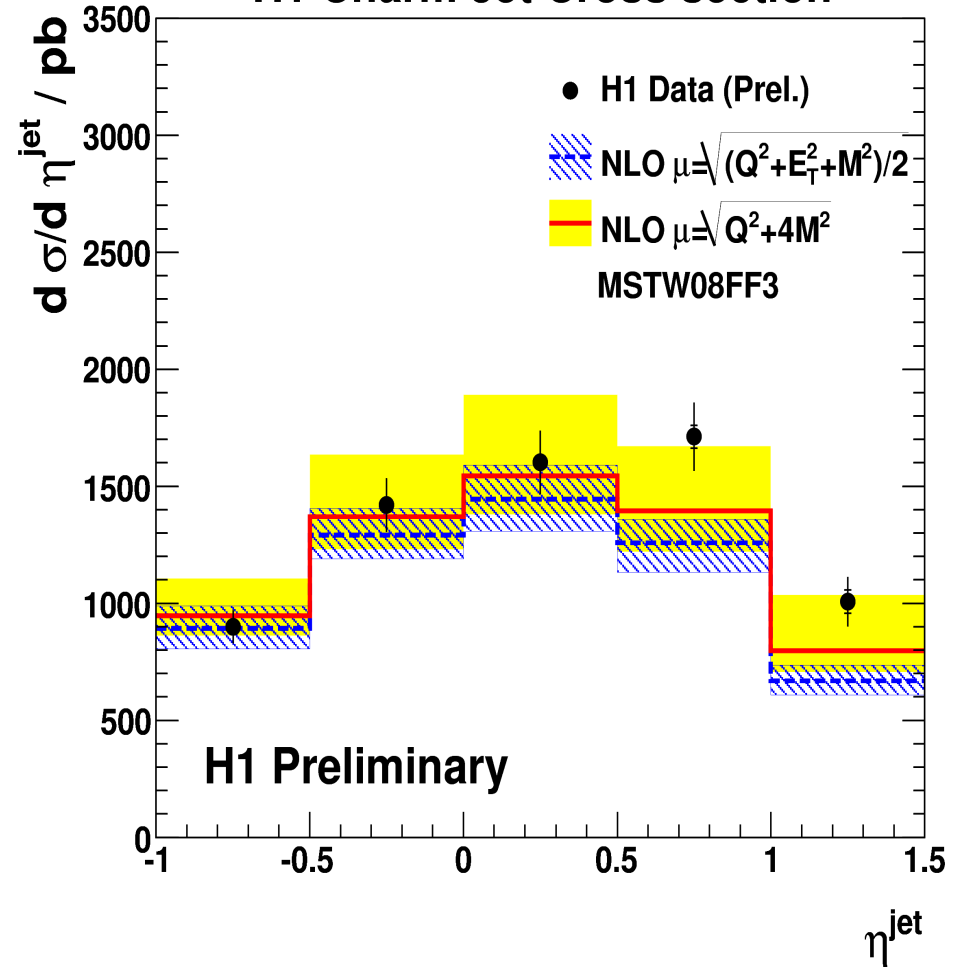
- Similar technique to Eur.Phys.J.C65:89-109, 2010 but with jet requirement

H1prelim-10-073

H1 Charm Jet Cross section



H1 Charm Jet Cross section

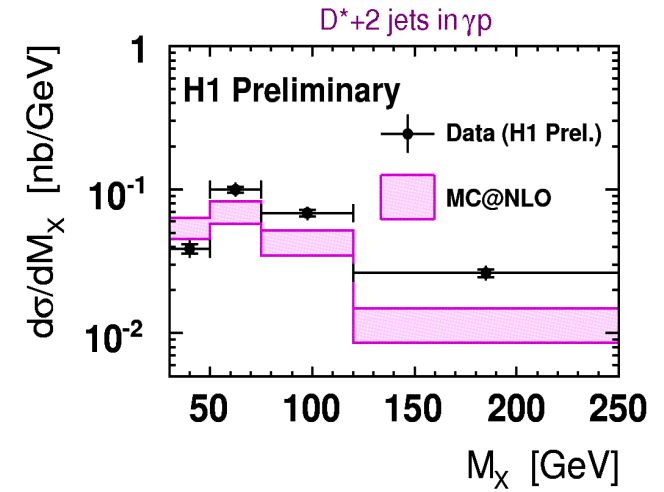
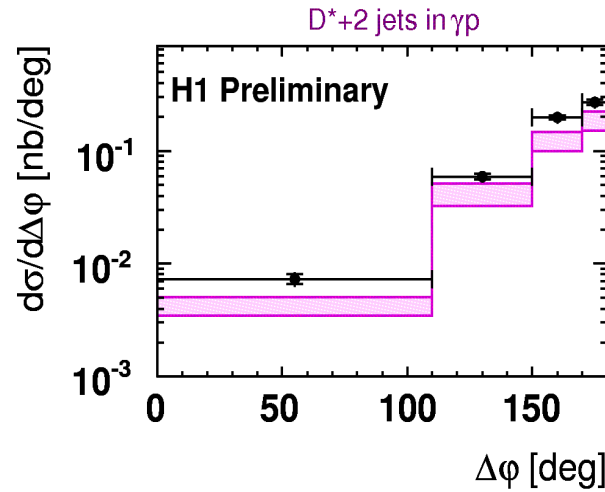
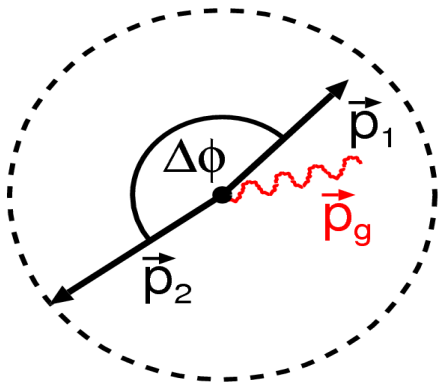


- Good agreement with NLO predictions
- More details – see talk by Michel Sauter

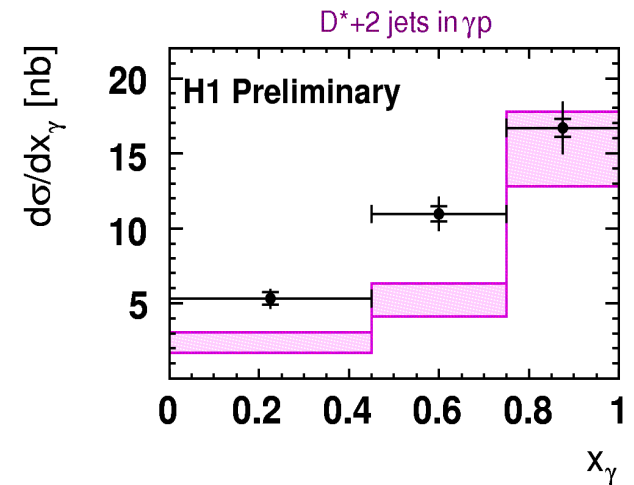
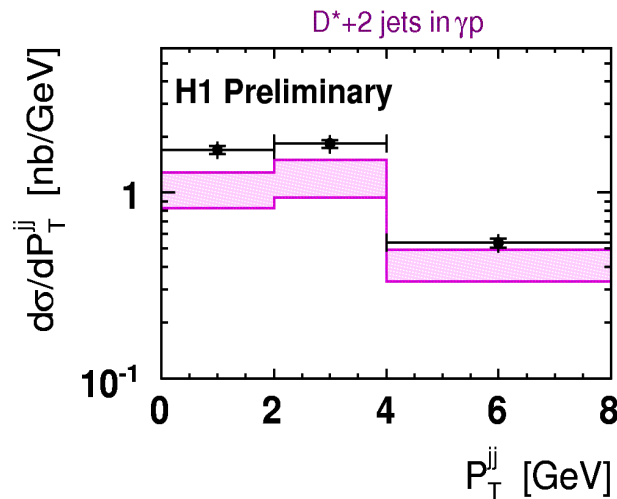
Photoproduction of D^* with jets

H1prelim-10-072

- Events with a D^* and 2 jets are required



- Asimuthal correlation $\Delta\Phi$ sensitive to the higher order effects



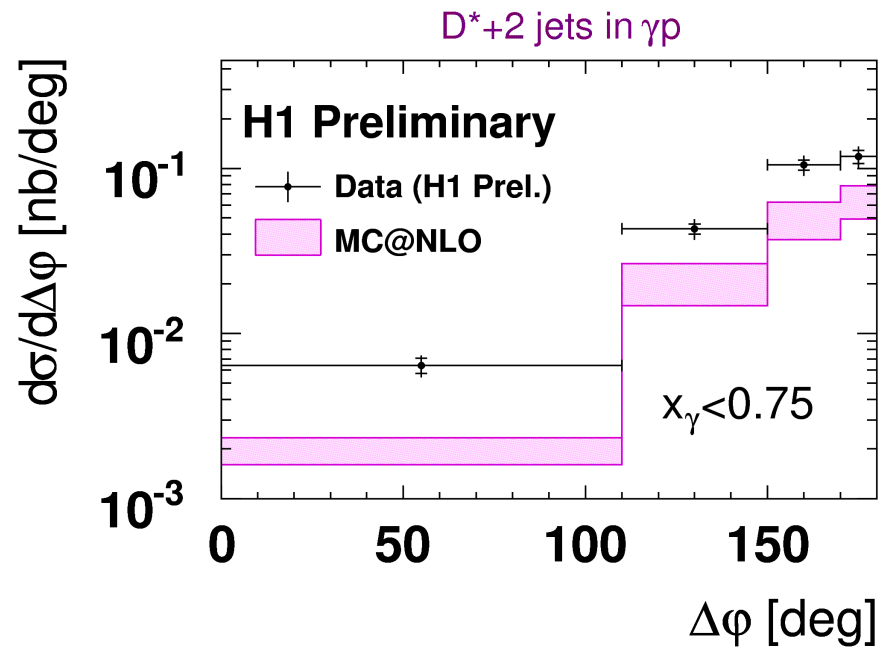
$$x_{\gamma}^{obs} = \frac{\sum_{Jet_1} (E - p_z) + \sum_{Jet_2} (E - p_z)}{\sum_h (E - p_z)}$$

- in LO, fraction of the photon energy entering hard interaction (direct VS¹⁹ resolved)

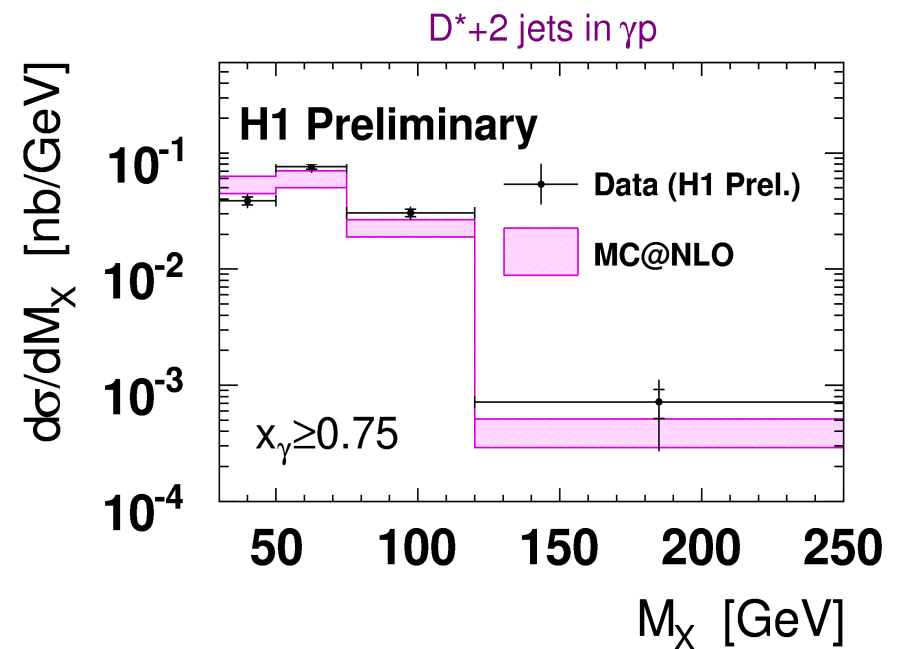
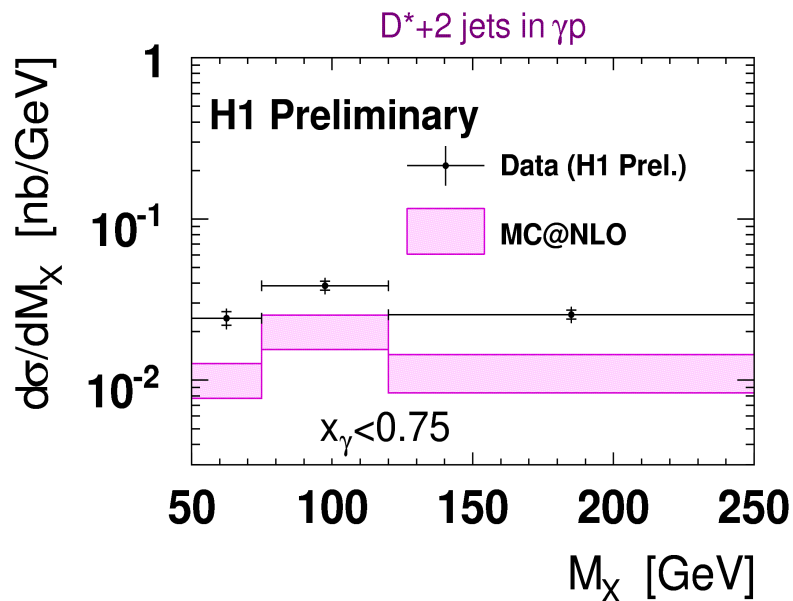
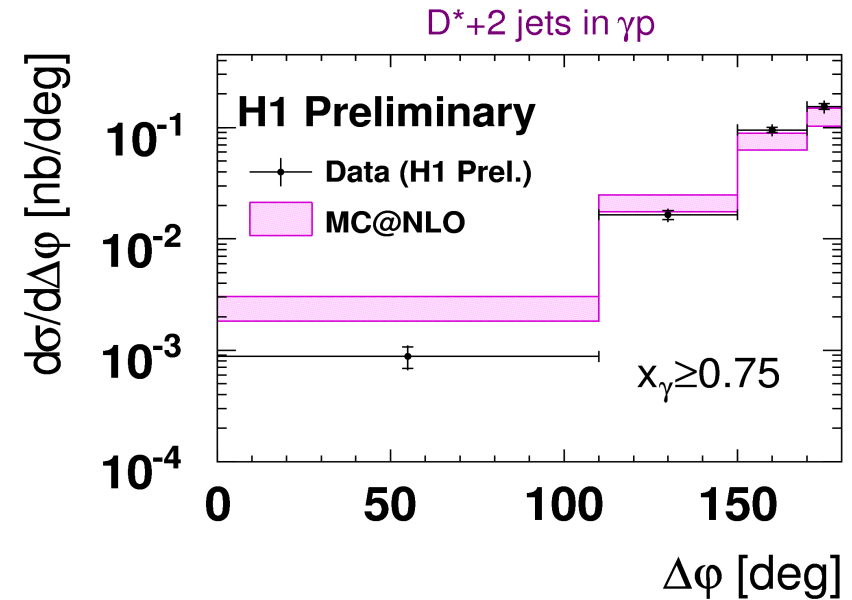
Photoproduction of D^* with jets

H1prelim-10-072

Resolved



Direct



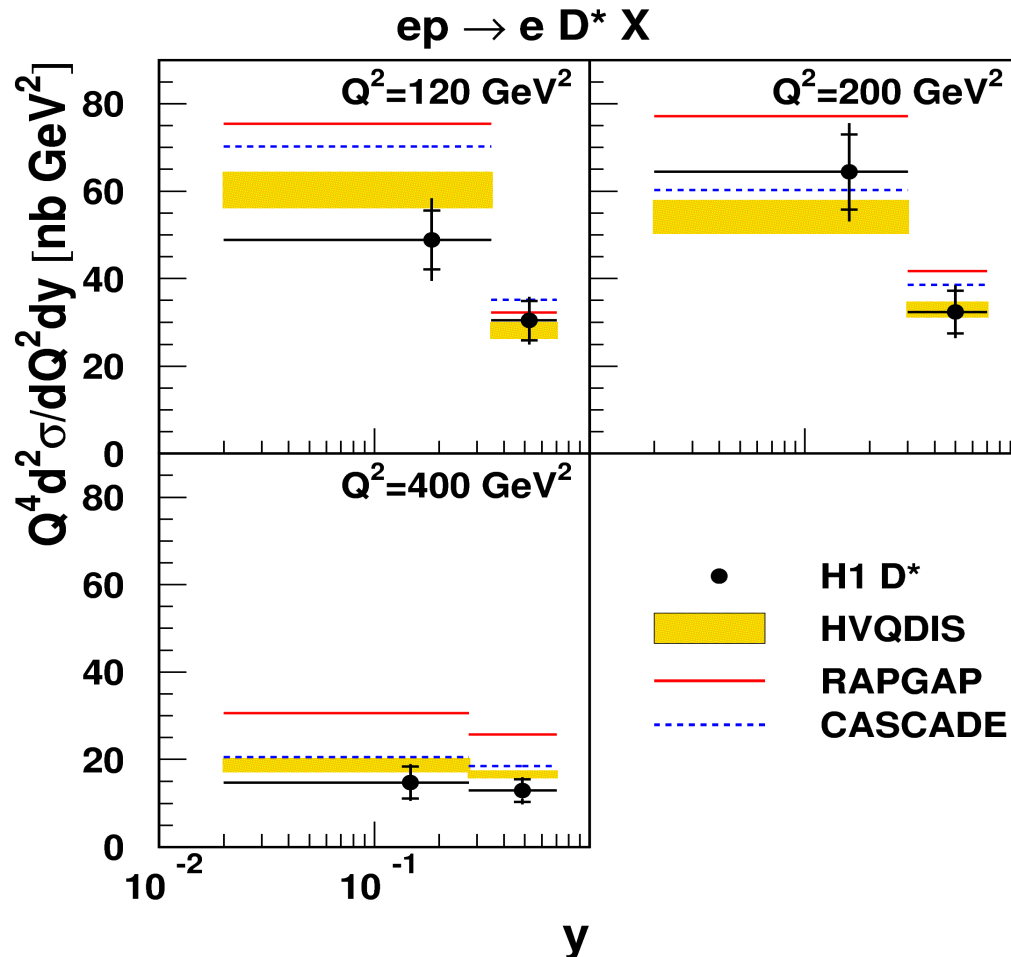
Summary and outlook

- 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

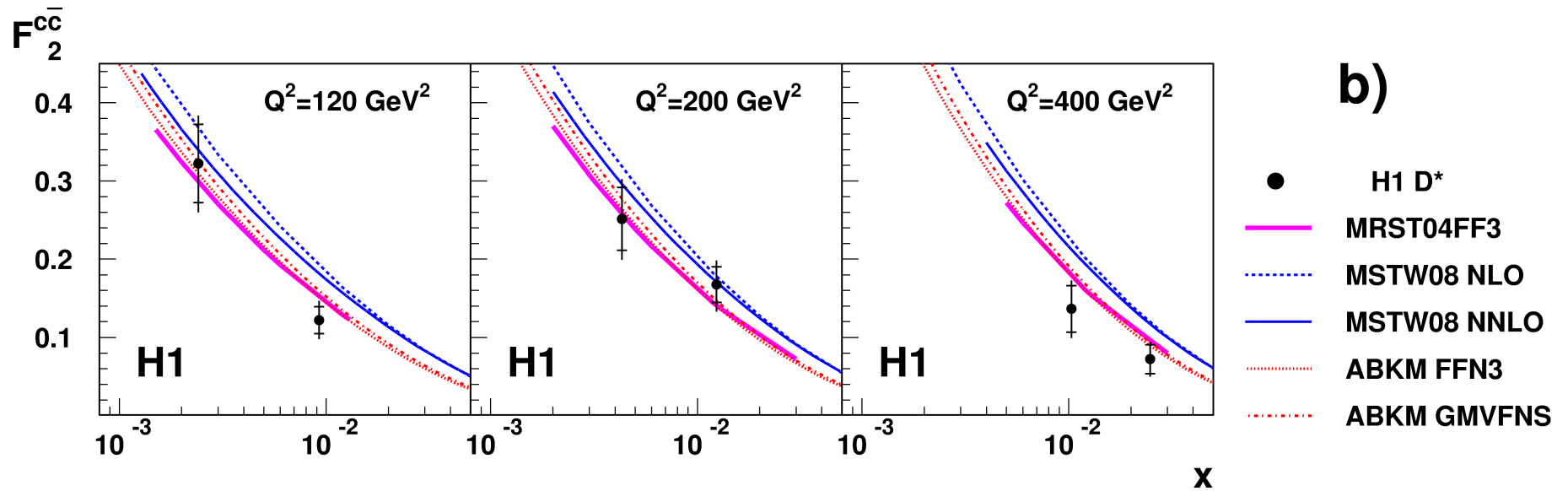
D* measurement in DIS at high Q²



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

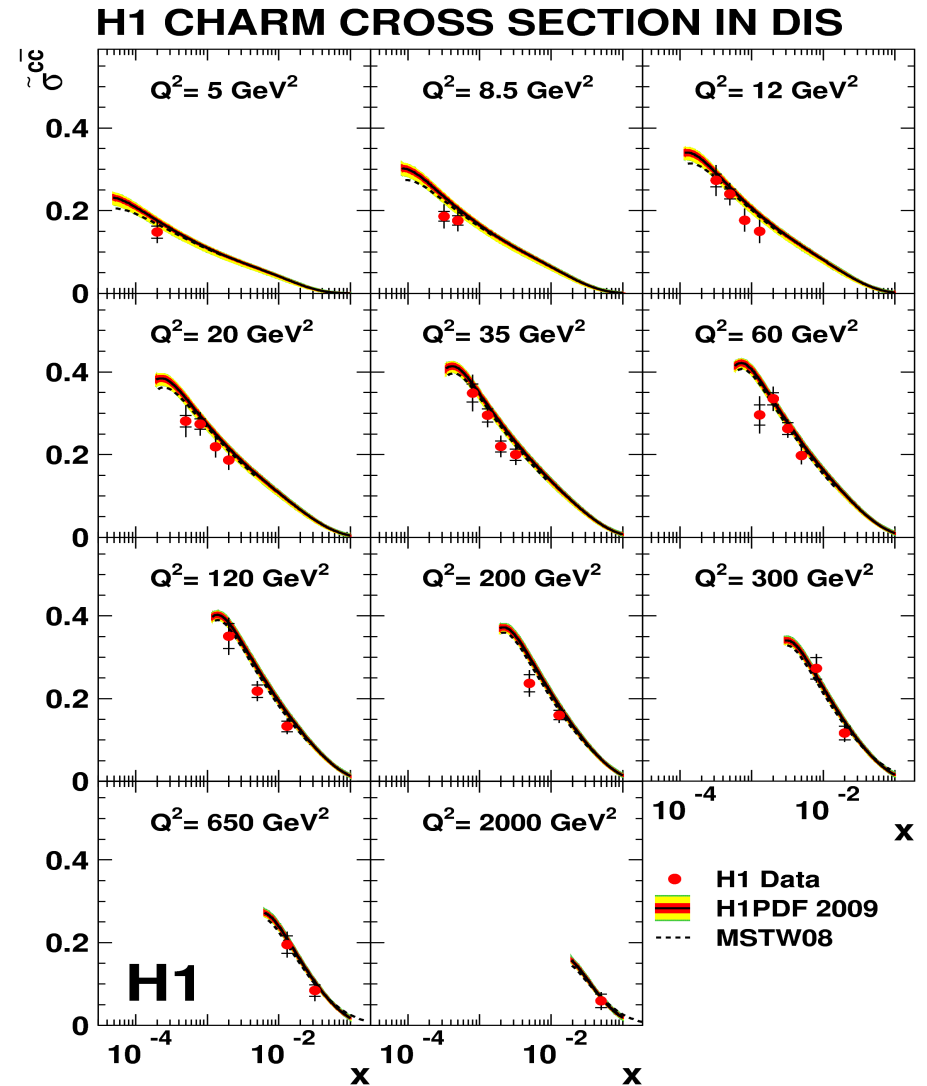
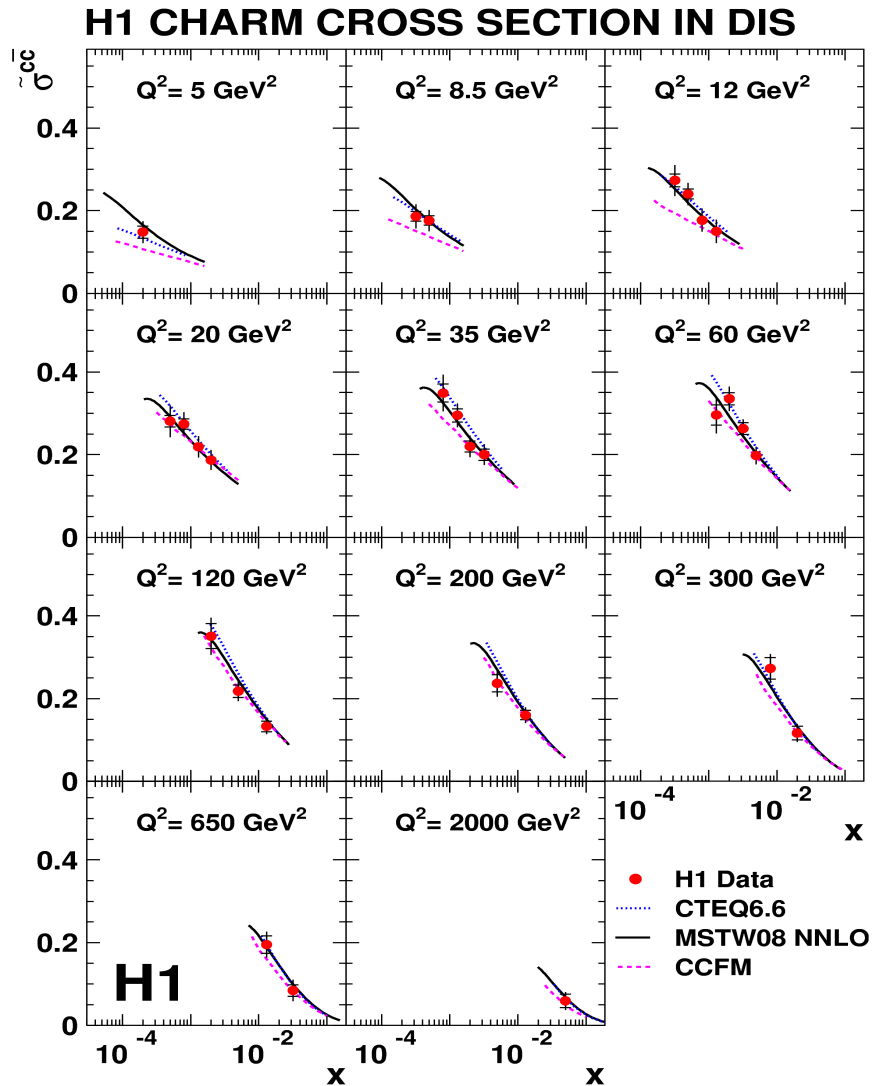
D* measurement in DIS: F_2^{cc}

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 Q^2 and x
- H1 and MSTW @ NLO – also a reasonable description

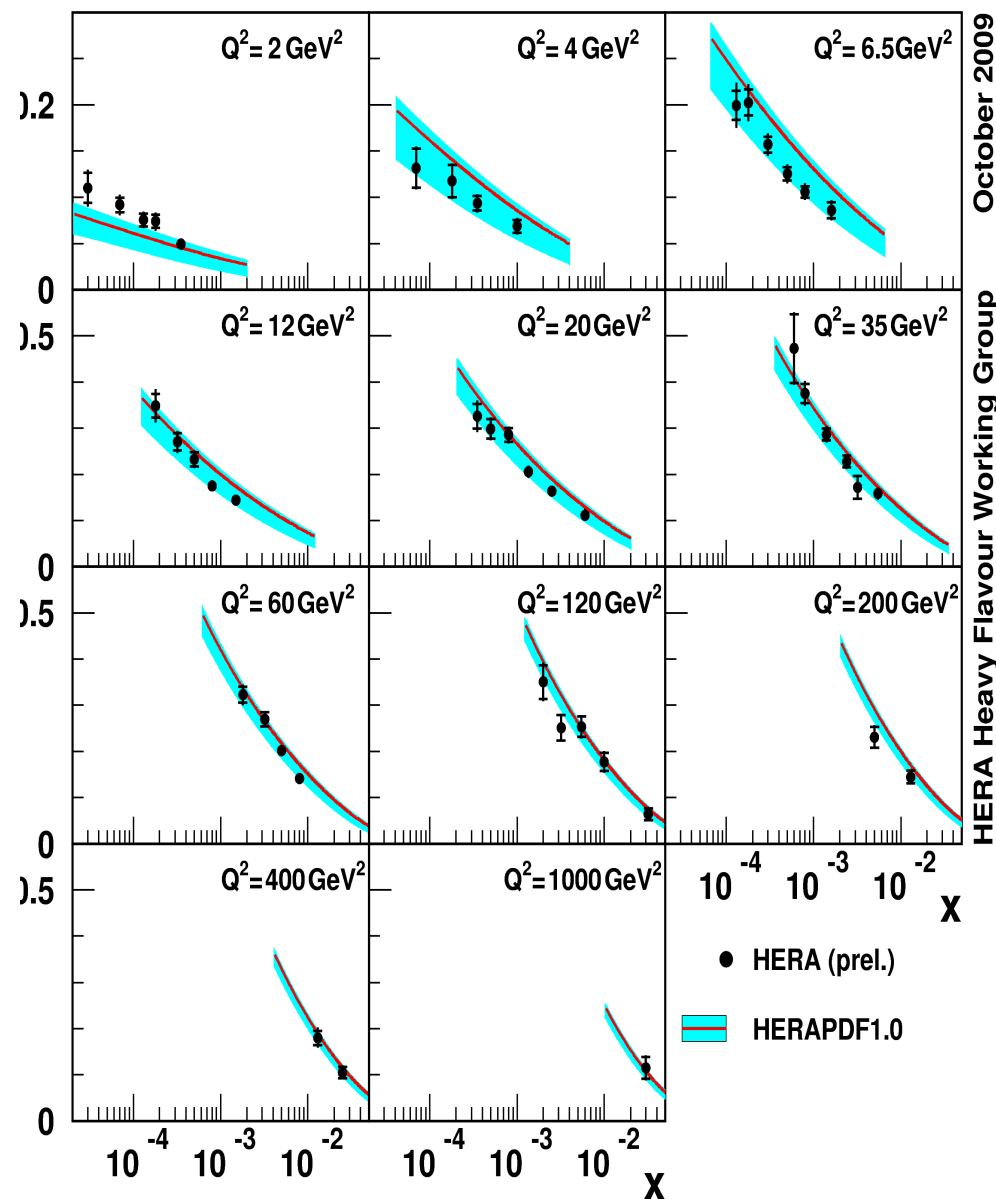
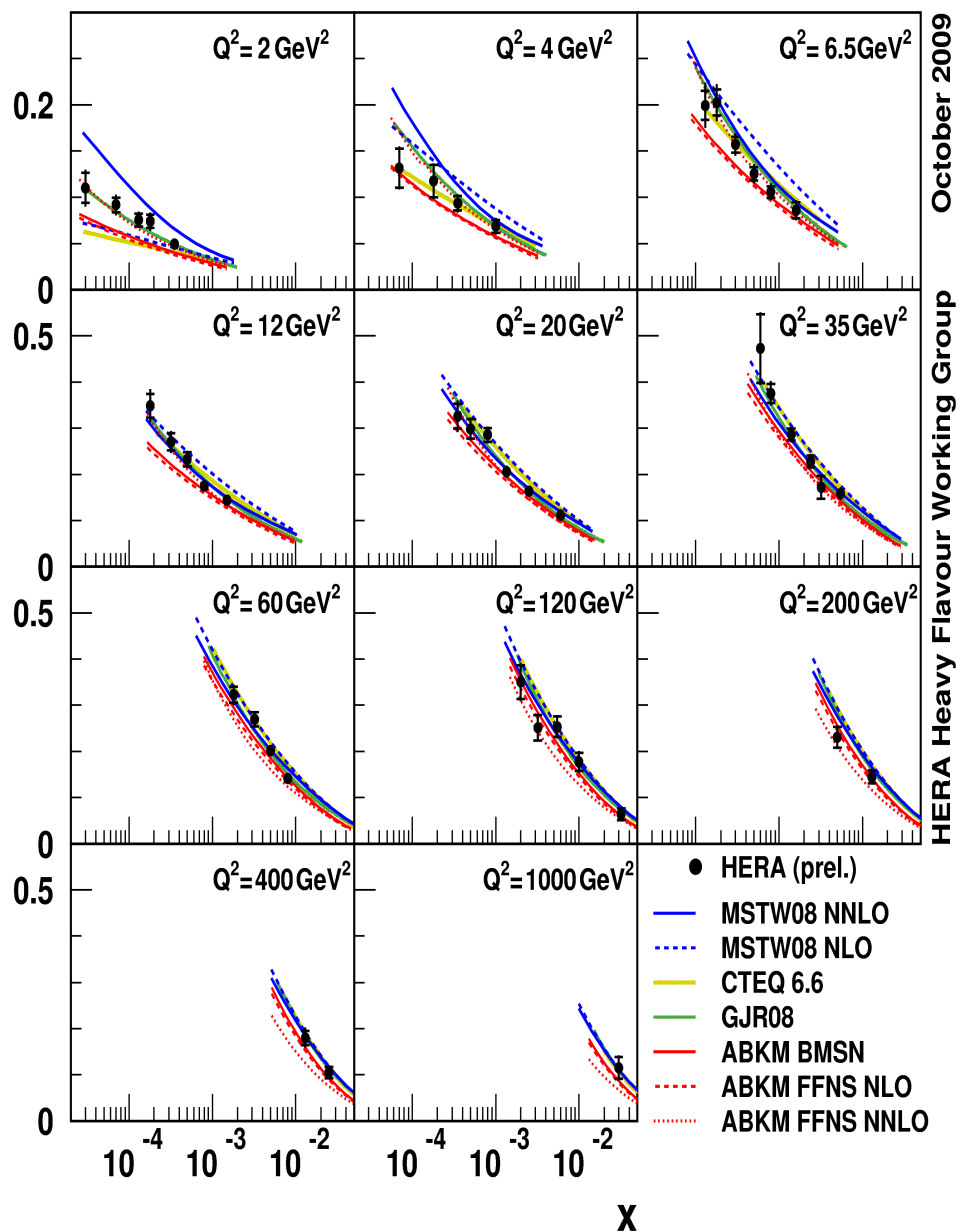
H1+ZEUS F_2^{CC} combination

ZEUS-prel-09-015

H1prelim-09-171

H1 and ZEUS

F_2^{CC}



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