

# Measurement of the $D^{*\pm}$ Meson Production and $F_2^{CC}$ at High $Q^2$ with the H1 Detector



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DIS 2010



- Charm production
- $D^*$  at high  $Q^2$
- Results
- Summary



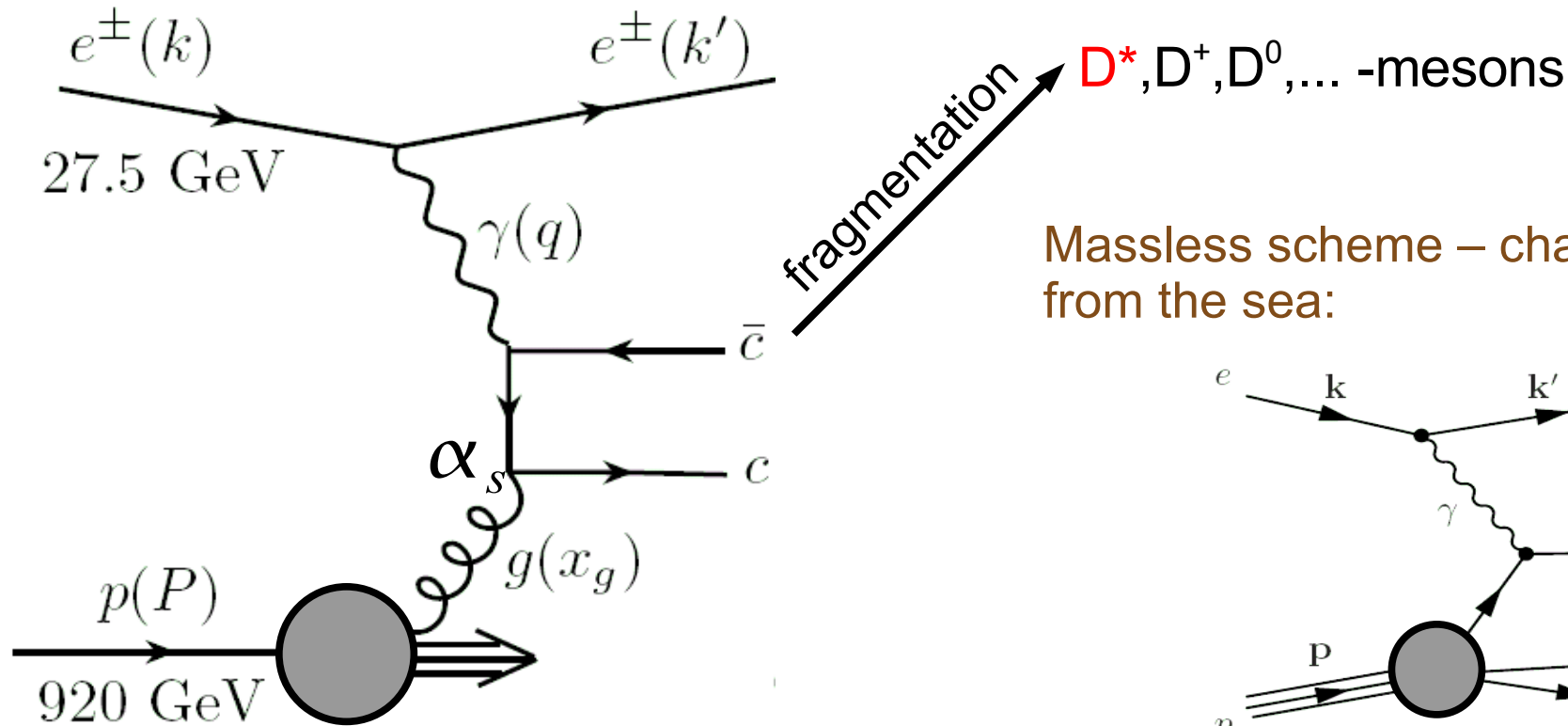
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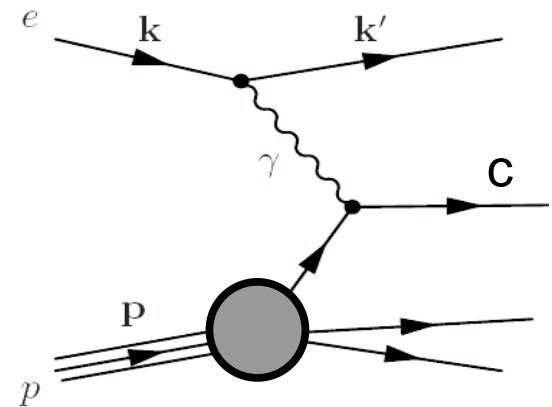
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and Research

# Charm Production at HERA

Dominant mechanism in the massive scheme:  
Boson Gluon Fusion (BGF)



Massless scheme – charm directly from the sea:



Charmed meson production cross section in QCD factorisation:

$$\sigma^{D^*} = \text{protonstructure (gluons)} \otimes \text{ME} \otimes \text{fragmentation}$$

Test different evaluation schemes for the hard ME at  $Q^2 \gg m_c^2$

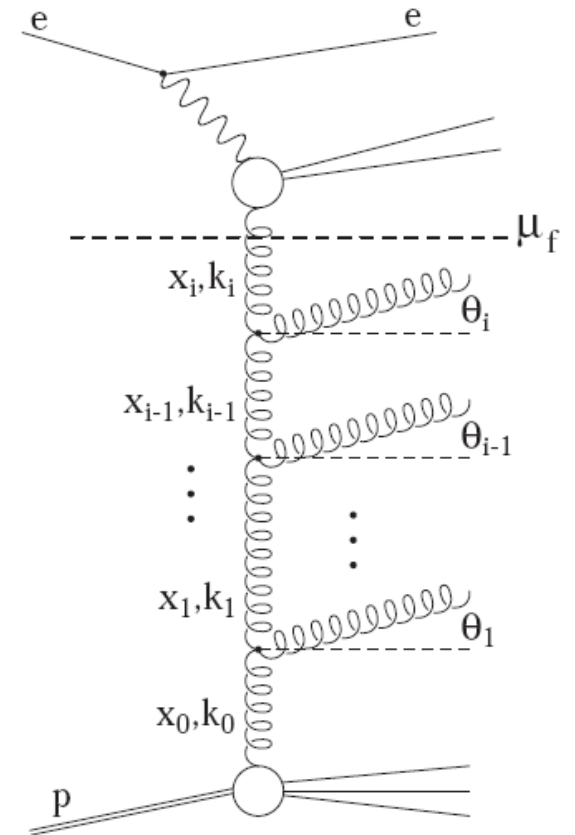
# Models for QCD Calculations

## NLO and NNLO calculations

- **HVQDIS (NLO):**
  - Massive (BGF) in 3-FFNS
  - DGLAP Evolution; set MRST2004FFF3 (CTEQ5F3)
  - Independent fragmentation (Kartvelishvili)
- **ZMVFNS calculation (NLO)**
  - PDF set: CTEQ6.6M
  - Fragmentation KKKS
- **GMVFNS calculation (NLO and NNLO)**
  - PDF set: MSTW08, ABKM

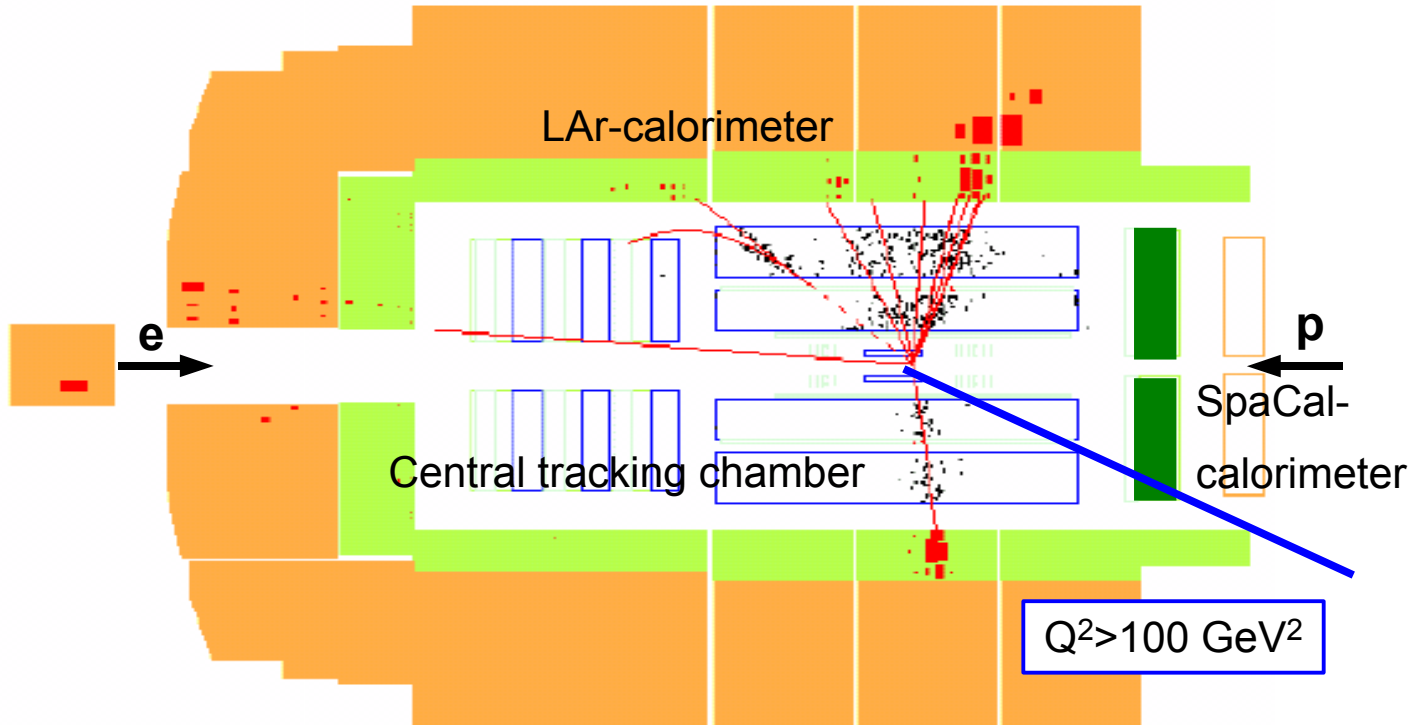
## Monte Carlo: LO + Partonshower

- Massive (BGF), 3-FFNS
- **RAPGAP:** DGLAP Evolution; set CTEQ6.5M (CTEQ6L)
- **CASCADE:** CCFM Evolution; set A0 (A2)
- Fragmentation (both MCs):
  - uds : Lund String Model; c,b : Kartvelishvili



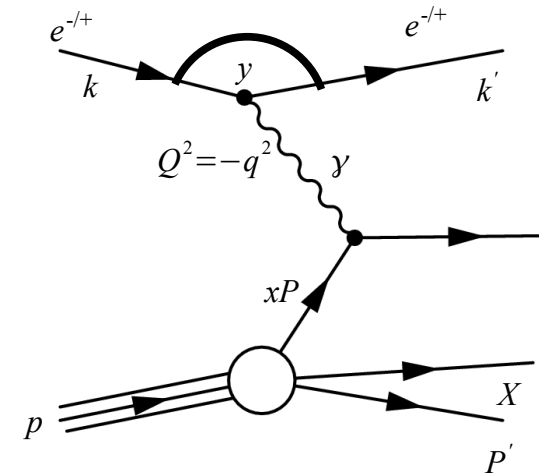
# Selection of the Analysis Sample

Data: HERAII,  $\mathcal{L}=351 \text{ pb}^{-1}$



- Scattered Electron: Cluster in LAr or SpaCal calorimeter
- Reconstruction of the  $D^*$  from the tracks in the central jet chamber

## Kinematics:



- Photon virtuality:

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

- Inelasticity:

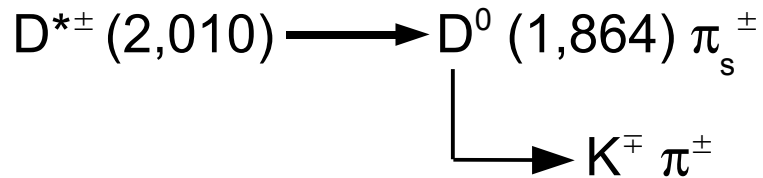
$$y = \frac{Pq}{Pk}$$

- Bjorken scale variable:

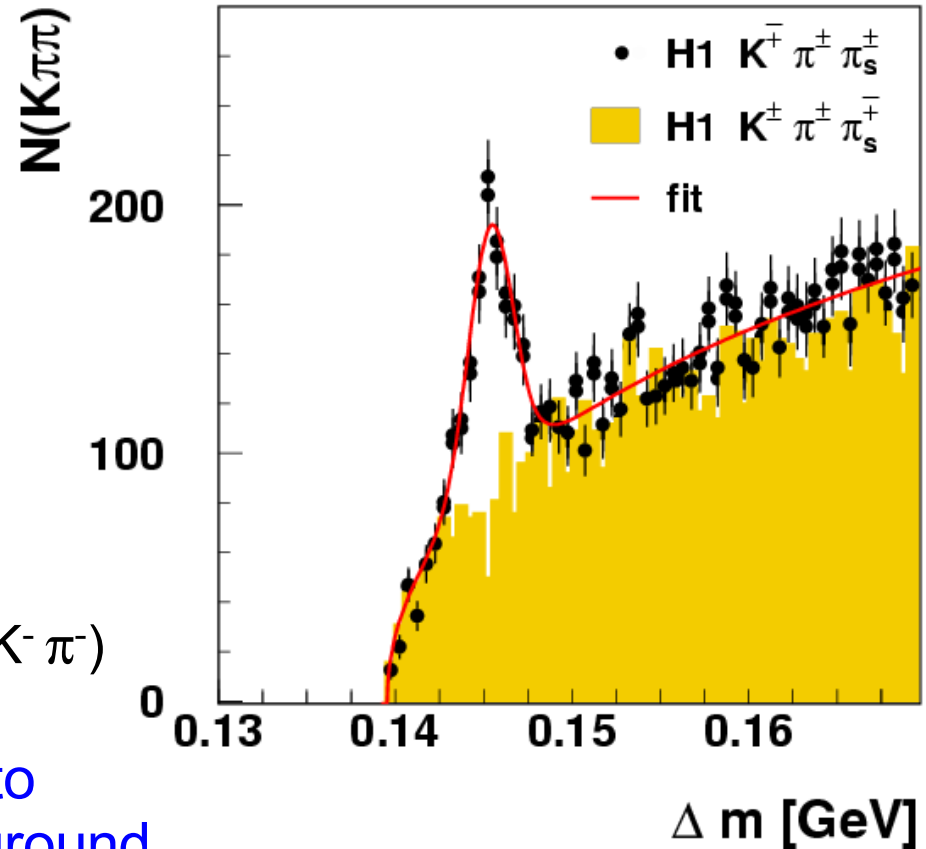
$$x = \frac{Q^2}{2Pq}$$

# D\* Reconstruction

- Select D\* in decay channel:



- Branching ratio BR=2.6%
- Use mass difference method:  
$$\Delta m(D^*) = M_{\text{inv}}(K\pi\pi_s) - M_{\text{inv}}(K\pi)$$
- Combinatorial background via doubly charged combinations ( $K^+ \pi^+ / K^- \pi^-$ )
- Signal extraction: simultaneous fit to signal and background



# Cross Section Measurement

Total cross section in the visible range:  $100 < Q^2 < 1000 \text{ GeV}^2$ ,  $0.02 < y < 0.7$

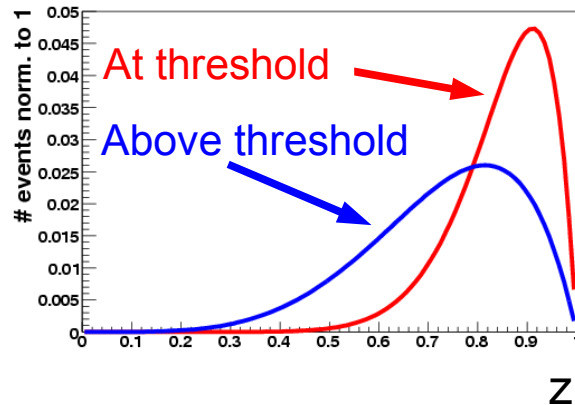
$p_T(D^*) > 1.5 \text{ GeV}$ ,  $-1.5 < \eta(D^*) < 1.5$

$$\sigma_{\text{tot}}(ep \rightarrow D^* X) = 225 \pm 14_{\text{stat}} \pm 27_{\text{syst}} \text{ pb}$$

Data Compared to HVQDIS prediction:  $\sigma_{\text{tot}}^{\text{theo}} = 241 \pm 15 \text{ (model) pb}$

Model Input parameters:

- PDF MRST2004FF3 (CTEQ5F3);  $1.3 < m_c < 1.7 \text{ GeV}$ ;  $0.5\mu < \mu_r = \mu_f < 2\mu$ ,  $\mu = \sqrt{Q^2 + 4m_c^2}$
- Use threshold dependent fragmentation (Kartvelishvili) as measured by H1:



$$D_Q^{D^*}(z) = N z^\alpha (1-z)$$

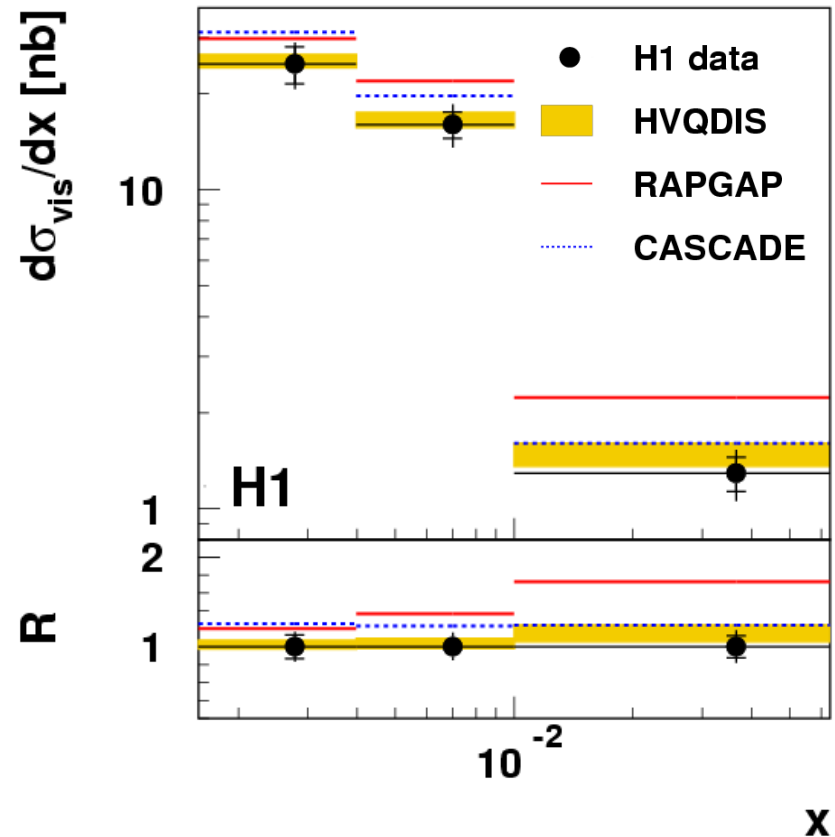
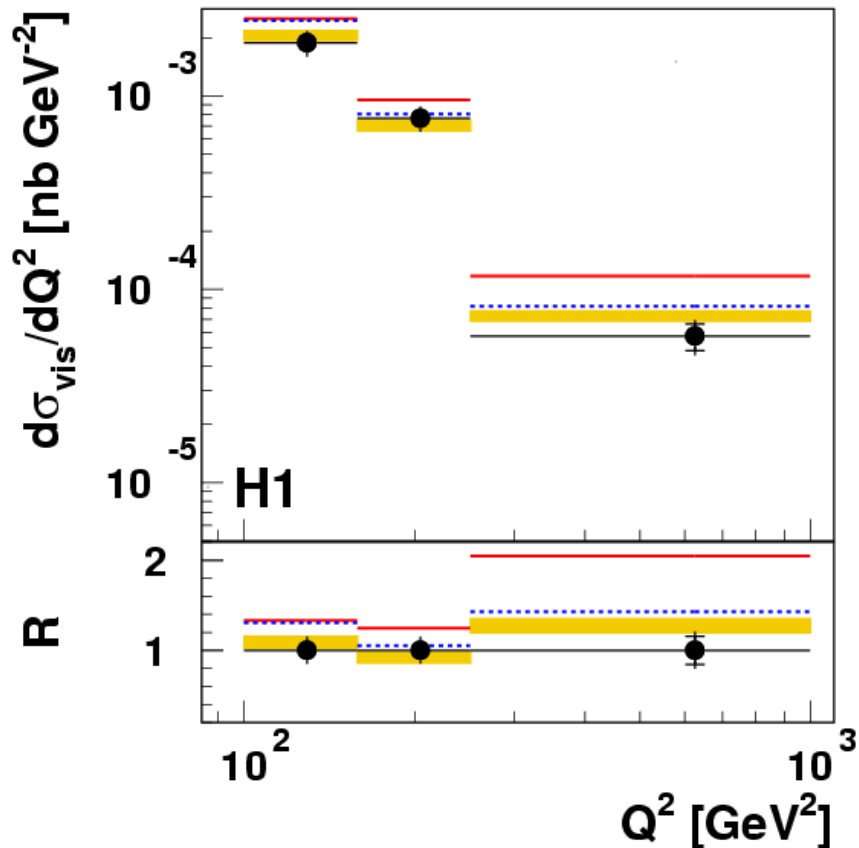
with

$$\alpha = 6.0_{-1.3}^{+1.1} \text{ for } \hat{s} < 70 \text{ GeV}^2$$

$$\alpha = 3.3_{-0.4}^{+0.4} \text{ for } \hat{s} > 70 \text{ GeV}^2$$

$\hat{s}$  - center of mass energy of the hard process

# Cross Sections – Event Kinematics

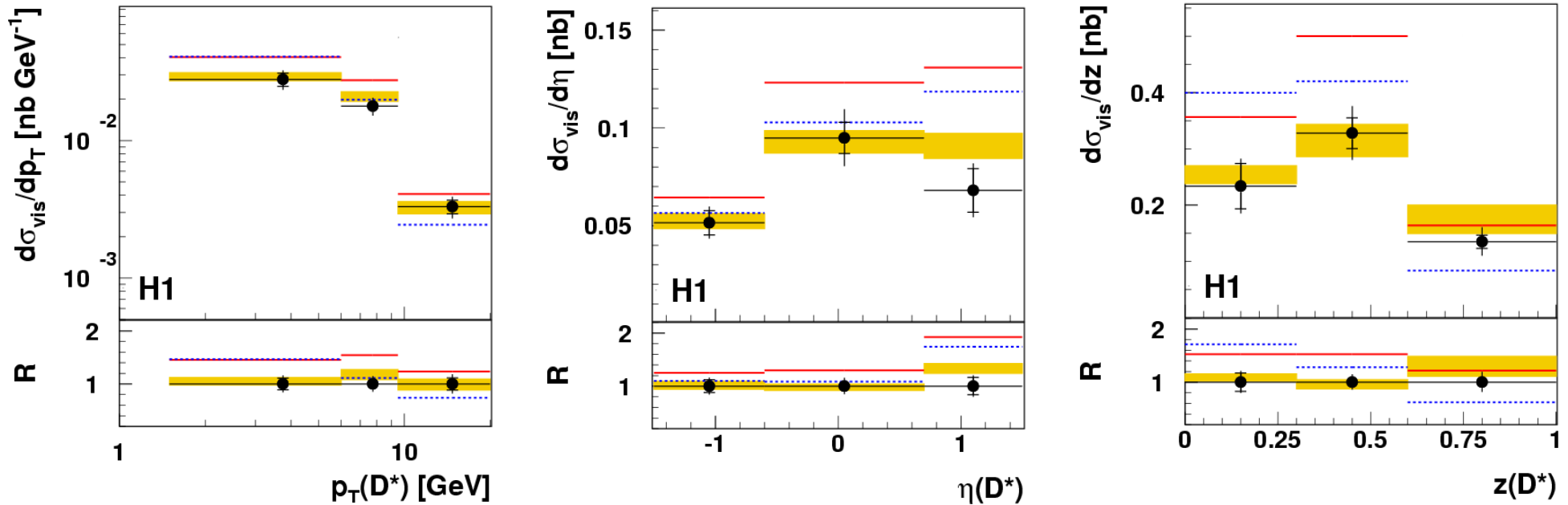


→ Massive NLO calculation describe data well despite  $Q^2 \gg m_c^2$

→ Monte Carlo predictions in leading order do not describe the data

# Cross sections – D\* Kinematics

- H1 data
- HVQDIS
- RAPGAP
- ⋯ CASCADE



→ Good agreement with HVQDIS

→ Monte Carlo predictions fail to describe the data

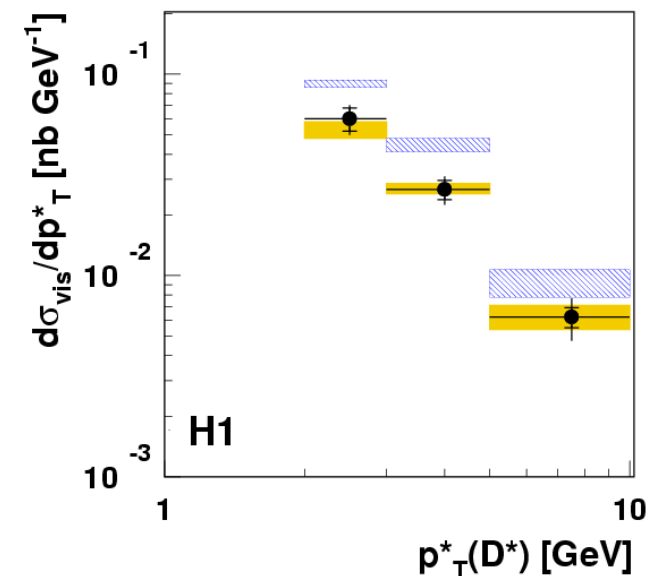
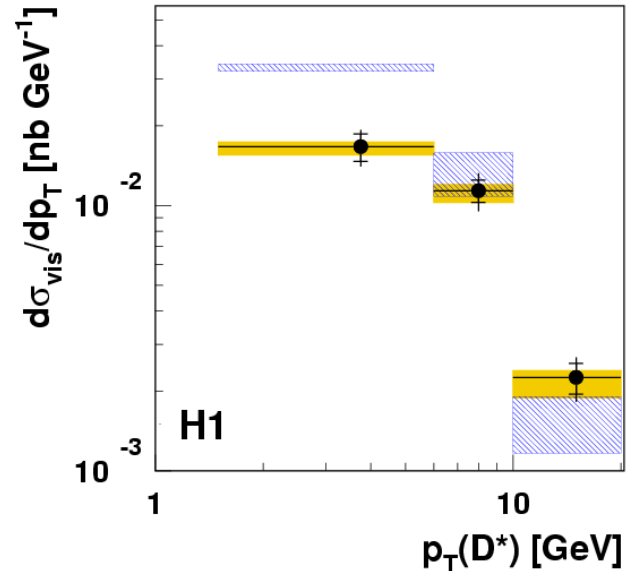
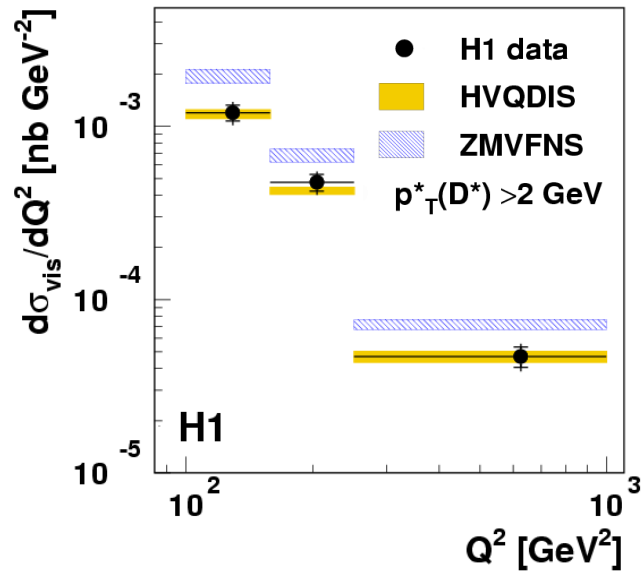
D\* inelasticity:

$$z_{D^*} = \frac{(E - p_z)_{D^*}}{2 y E_e}$$



# Test of the NLO Predictions

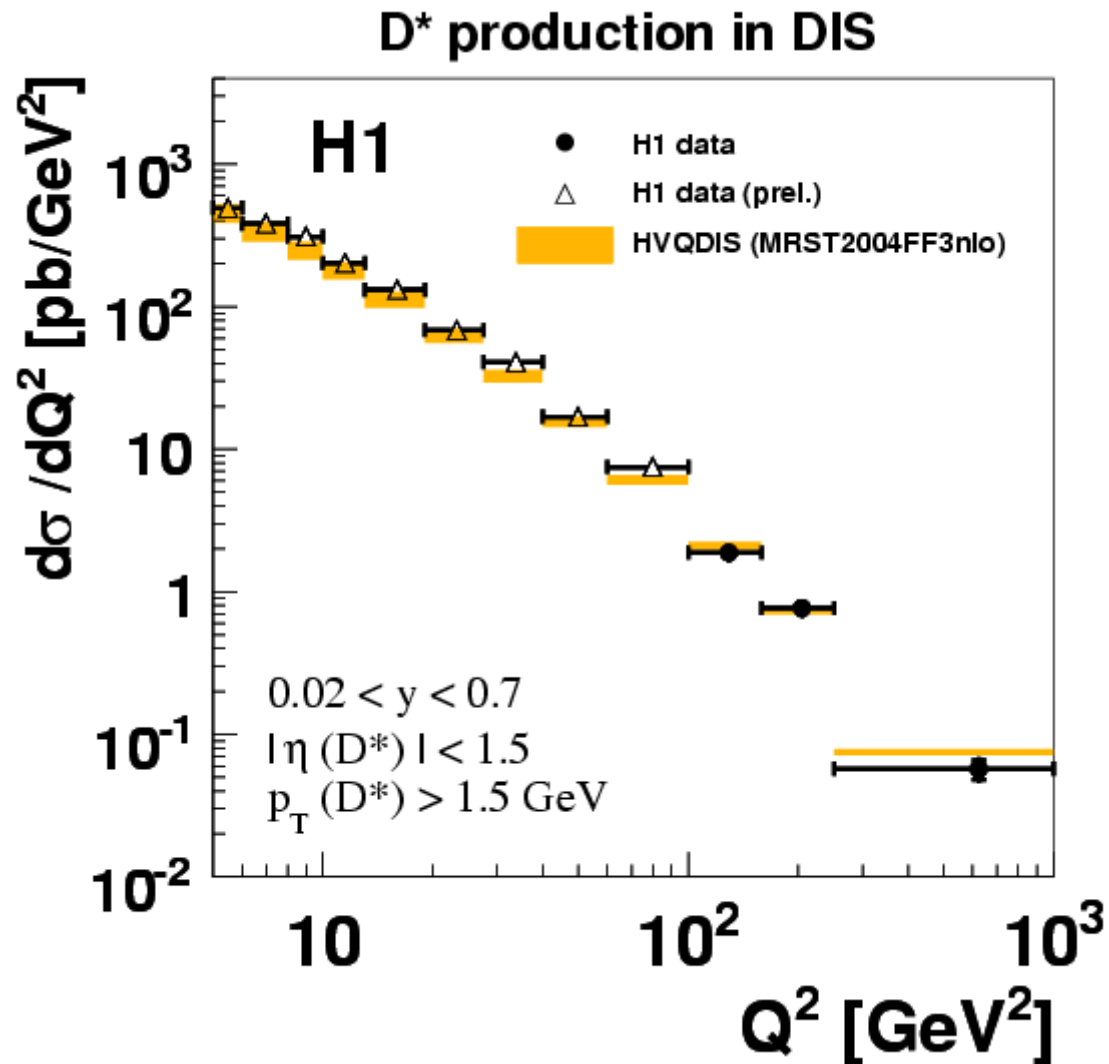
- For validity of ZMVFNS calculations  $p_t^*(D^*) > 2$  GeV is required ( $p_t^*(D^*)$ : transverse momentum of the  $D^*$  in the  $\gamma p$  – system)
- Comparison with data in this limited phase space



→ Massive predictions fit well

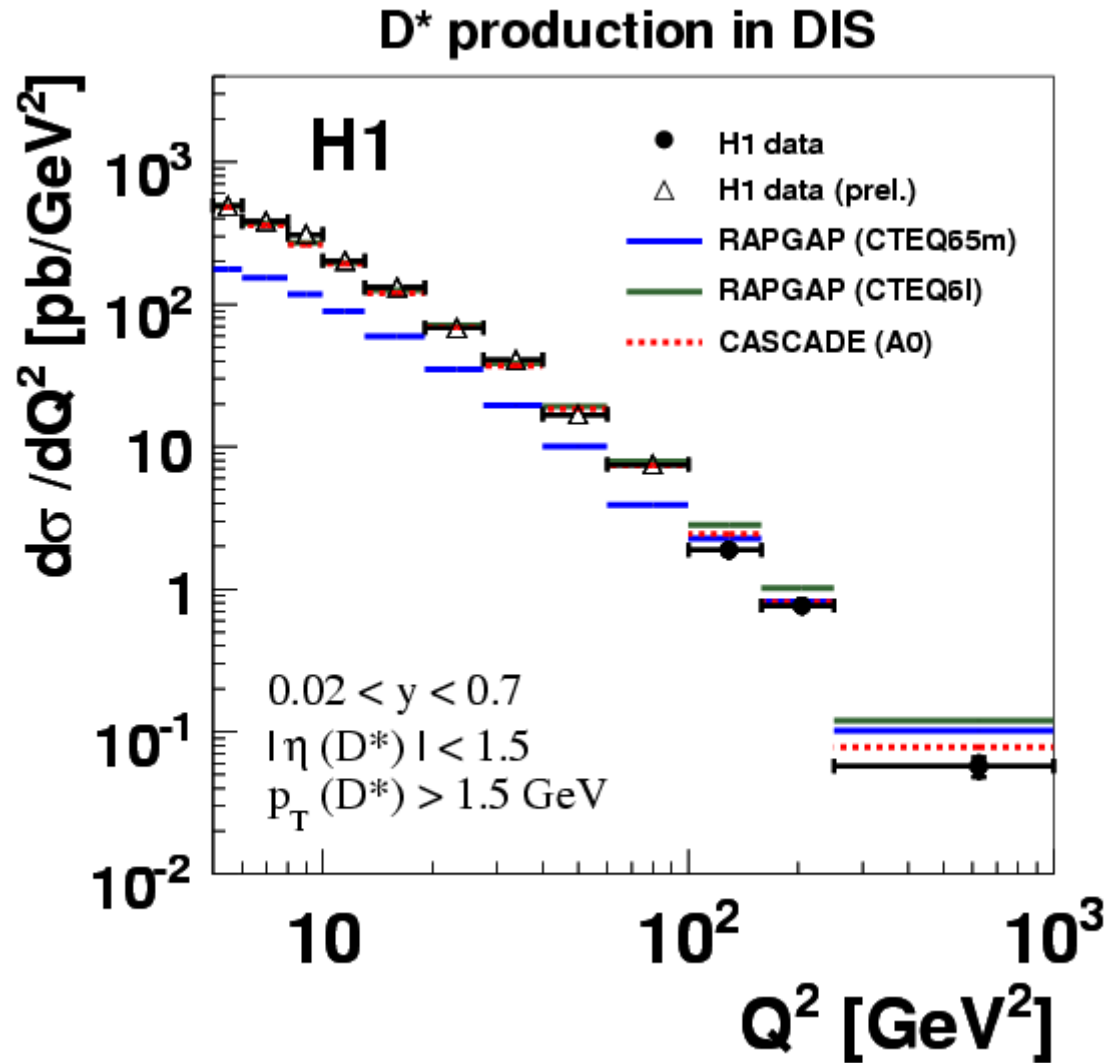
→ ZMVFNS predictions do not describe the data in form and normalisation.

# Cross Sections in full $Q^2$ Range



→ Reasonable description of  $Q^2$  slope by the massive calculation  
HVQDIS for  $5 < Q^2 < 1000 \text{ GeV}^2$

# Cross Sections in full $Q^2$ Range

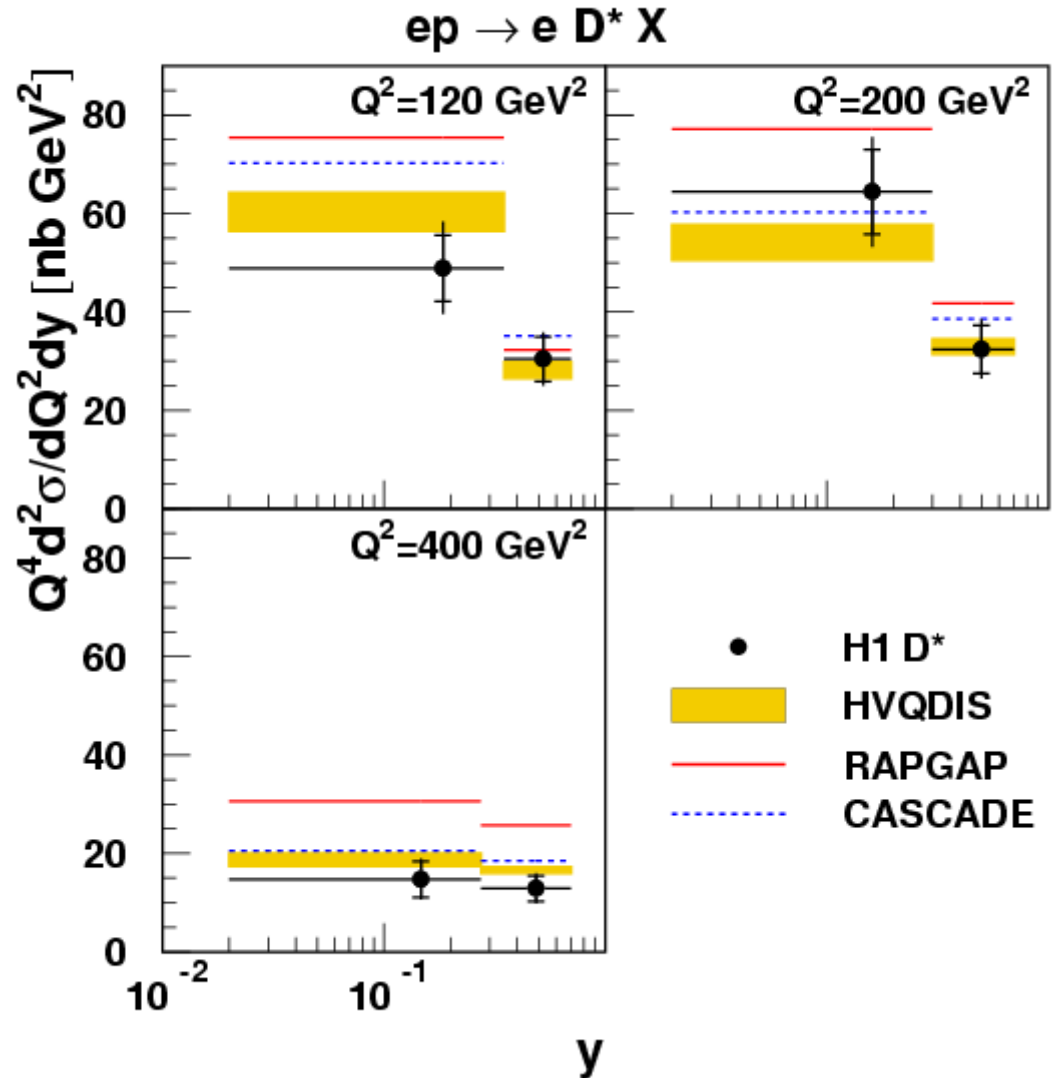


- **CASCADE (LO+PS CCFM):** reasonable description of the data
- **RAPGAP (LO+PS DGLAP):** both PDFs don't describe data well

# Cross Sections – Double differential in $(Q^2, y)$

- HVQDIS describes data well
- CASCADE prediction differs from data in 1.  $Q^2 y$  bin
- RAPGAP prediction too high

- Use double differential cross sections for extraction of  $F_2^{cc}$



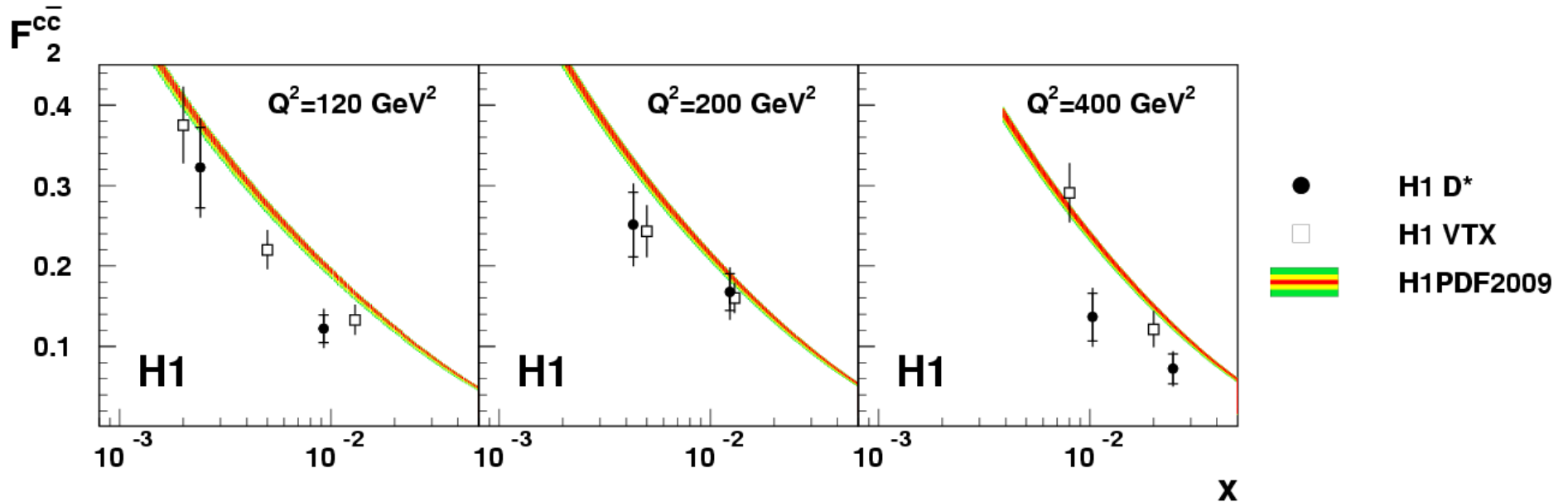
# Charm Contribution $F_2^{cc}$ to $F_2$

- Definition of  $F_2^{cc}$  :

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

Contribution of  $F_L^{cc}$  (~3%)  
neglected !

- Extrapolation in  $p_t(D^*)$  and  $\eta(D^*)$  with NLO QCD (HVQDIS) –  $(\sigma_{tot}/\sigma_{vis})$  : 1.4 – 2.3

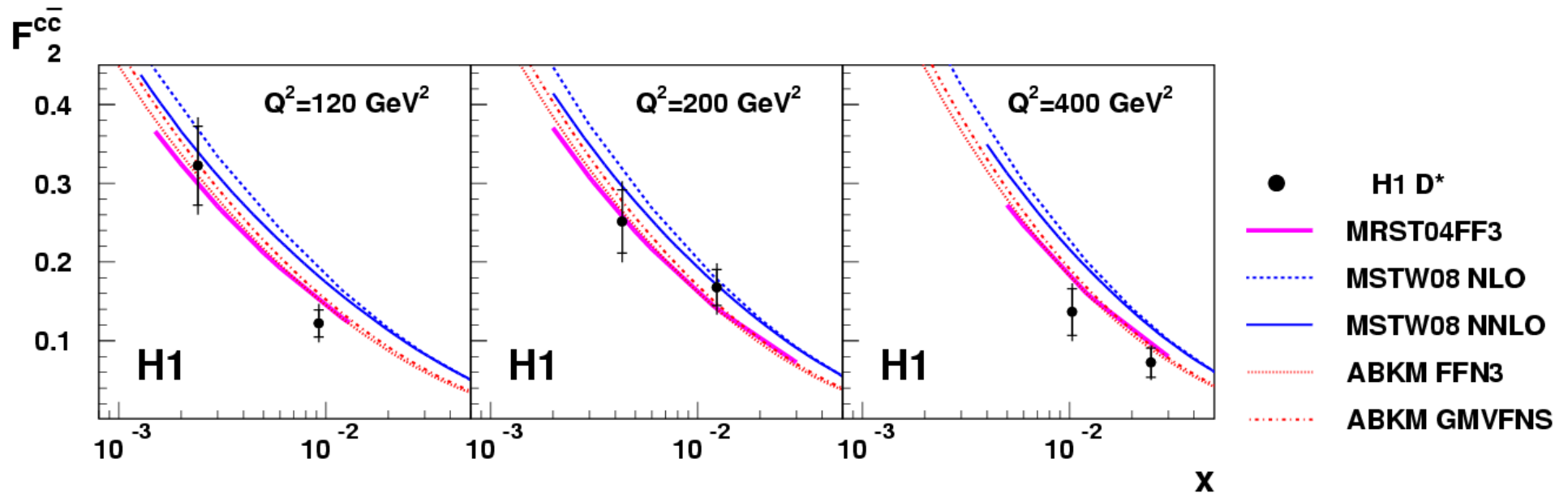


→ Overall agreement with results from charm identification via lifetime tag (with H1 vertex detector)

→ H1 PDF fit H1PDF2009 (inclusive DIS data) above  $D^*$  measurement

# Results of $F_2^{cc}$ in Comparison to QCD Predictions

- Charm contribution on total DIS cross section up to 30% @ high  $Q^2$
- Test different schemes for treatment of heavy quarks in PDF fits



→ Measured  $F_2^{cc}$  consistent with predictions within errors

- Measurement used in H1 ZEUS combination of  $F_2^{cc}$  !

# Summary

- Charm production for  $Q^2 > 100 \text{ GeV}^2$  investigated via measurement of  $D^*$  meson production cross sections
- Allows test of perturbative QCD in this region of phase space
  - **Good agreement with massive calculation based on BGF in NLO also at  $Q^2 \gg m_c^2$**
  - **Data are not described by massless calculations (ZMVFNS)**
  - **LO+PS Monte Carlo predictions differ from data**
- $F_2^{\text{cc}}$  extracted at high  $Q^2$ .
- Measurement contributes to H1ZEUS Combination of  $F_2^{\text{cc}}$  at high  $Q^2$