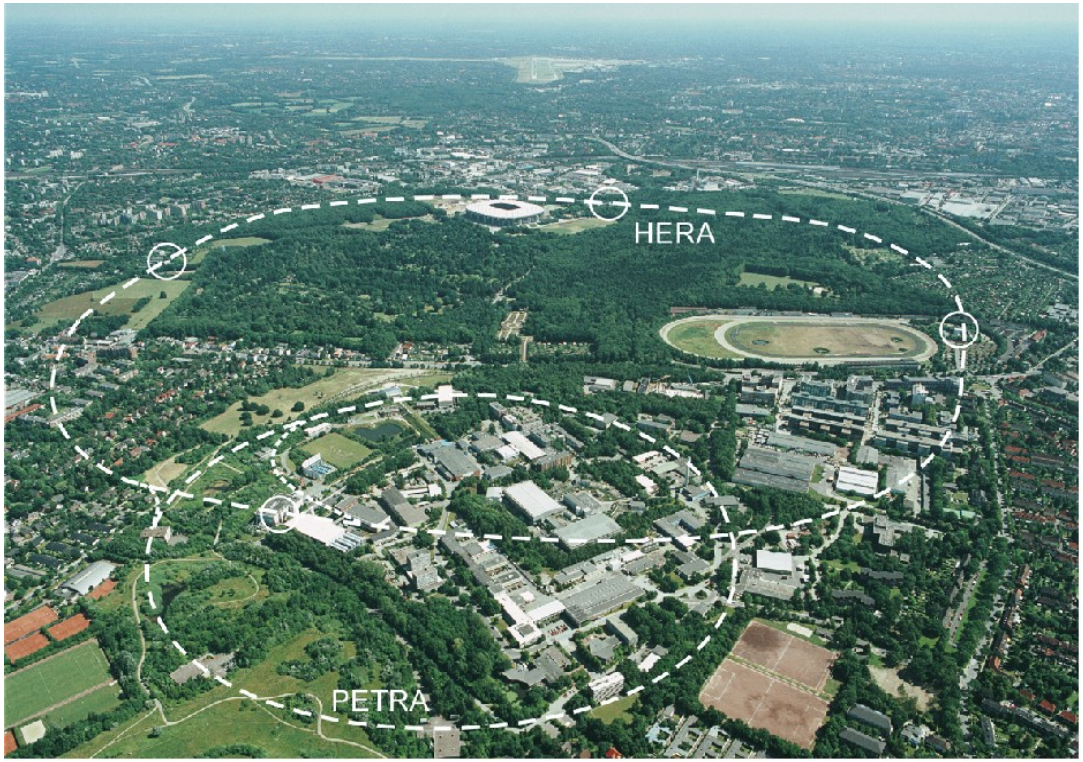
Measurement of $D^{*\pm}$ Meson Production and Determination of F_2^{cc} at low Q^2 in Deep-Inelastic Scattering at HERA

Eur.Phys.J.C71:1769,2011.



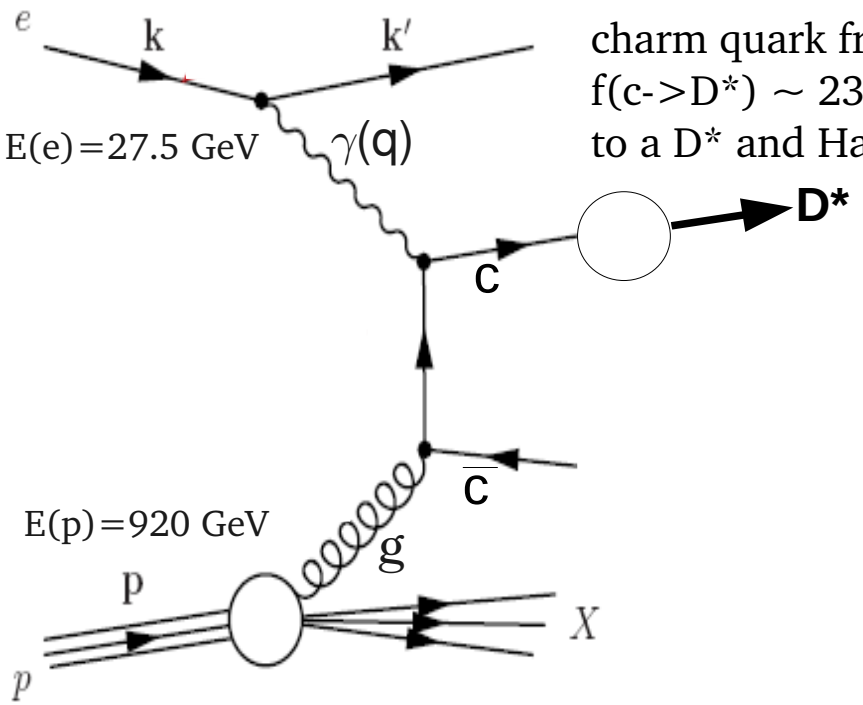
- Introduction
- D* meson cross sections
- $F_2^{c\bar{c}}$
- Conclusions

Eva Hennekemper (KIP, Universität Heidelberg)
on behalf of the H1 collaboration

XX International Workshop on Deep-Inelastic Scattering and Related Subjects
March 26-30,2012, Bonn, Germany

D* Production

charm quarks predominantly produced in **boson gluon fusion**:



charm quark fragments with
f(c->D*) ~ 23.5%
to a D* and Hadrons.

Event Kinematics:

$\sqrt{s}$ =320 GeV

Photon virtuality: $Q^2 = -q^2 = -(k - k')^2$

Inelasticity: $y = (q \cdot p)/(k \cdot p)$

Bjorken x: $x = Q^2 / 2(p \cdot q)$

Kinematic variables of the D*:

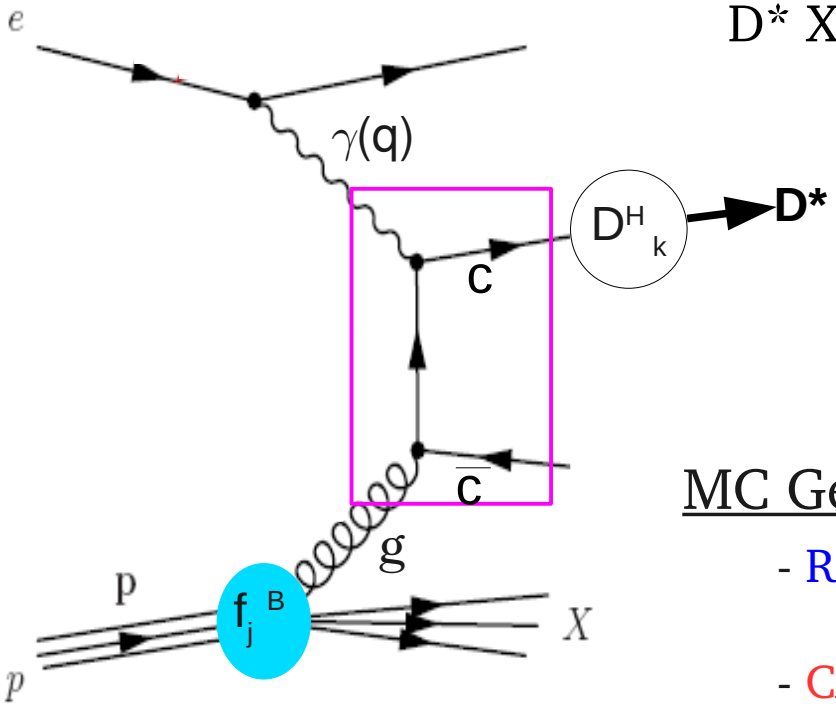
Transverse momentum: $p_T(D^*)$

Transverse momentum in γp frame: $p_T^*(D^*)$

Pseudorapidity: $\eta(D^*) = -\ln(\tan \theta/2)$

D* Elasticity: $z(D^*) = \dfrac{p(p) \cdot p(D^*)}{p(p) \cdot q}$

QCD Models and MC Simulation



D* Xsection can be calculated via a Factorisation ansatz:

$$d\sigma_{D^*} = \sum_{ijk} f_j^B(x_2,\mu_f) \otimes d\sigma_{ij\to kX}(\mu_f) \otimes D_k^H(z,\mu_f)$$

Parton density functions (from global fits)

Matrix element

Fragmentation function (from Data)

MC Generators based on LO(α_s) QCD calculations + PS:

- RAPGAP: collinear factorization, DGLAP, FFNS, massive c quark, Pdf: CTEQ6.6M, CTEQ6LL
- CASCADE: k_t factorization, CCFM, FFNS, massive c quark, Pdf: A0

Both for **Fragmentation**: Lund String Model(uds), Kartvelishvili(c)

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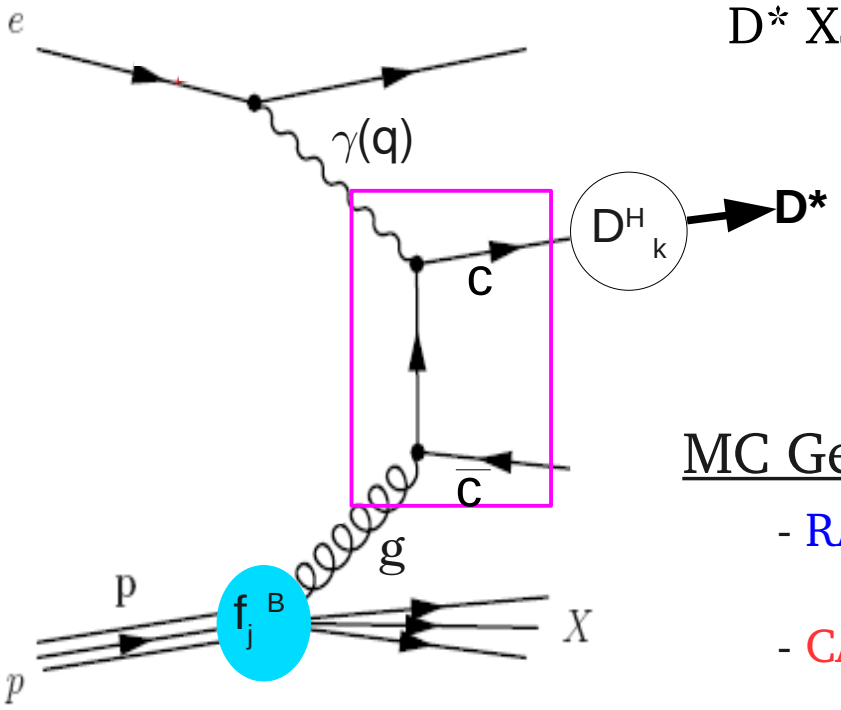

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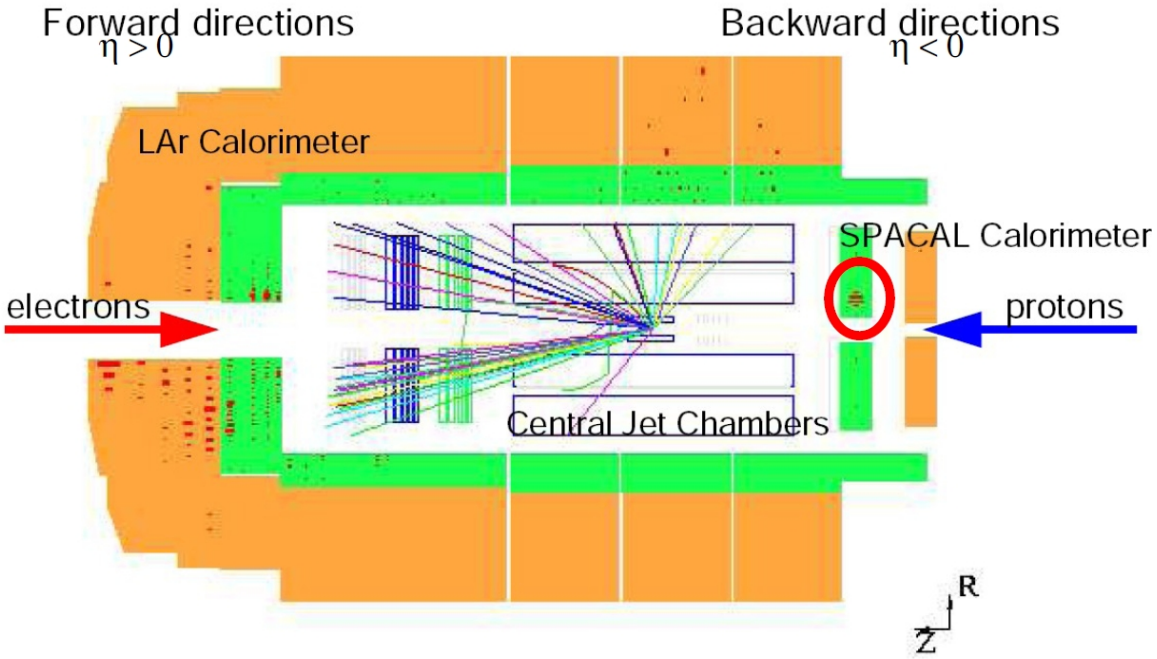
NLO(α_s) calculations:

-HVQDIS: collinear factorization, DGLAP, FFNS (massive charm produced in BGF), **Fragmentation:** Kartvelishvili, PDF: CT10f3 (FFNS, NLO), MSTW2008f3

-ZM-VFNS calculation: collinear factorization, DGLAP, ZM-VFNS (massless charm in proton), **Fragmentation:** KKKS08, PDF: CTEQ6.6M

Event Selection and Signal Extraction

Events triggered by detecting
scattered electron in SPACAL calorimeter.



Kinematic range:

$5 < Q^2 < 100\ \mathrm{GeV}^2$
$0.02 < y < 0.7$
$-1.8 < \eta(D^*) < 1.8$
$p_T(D^*) > 1.25\ \mathrm{GeV}$

Golden Decay Channel:

$$D^{*\pm} \rightarrow D^0 \pi^{\pm}_{slow} \rightarrow (K^{\mp}\pi^{\pm})\pi^{\pm}_{slow}$$

Branching fraction $BR = 2.63\%$

Tracks reconstructed in
Central Jet Chambers.

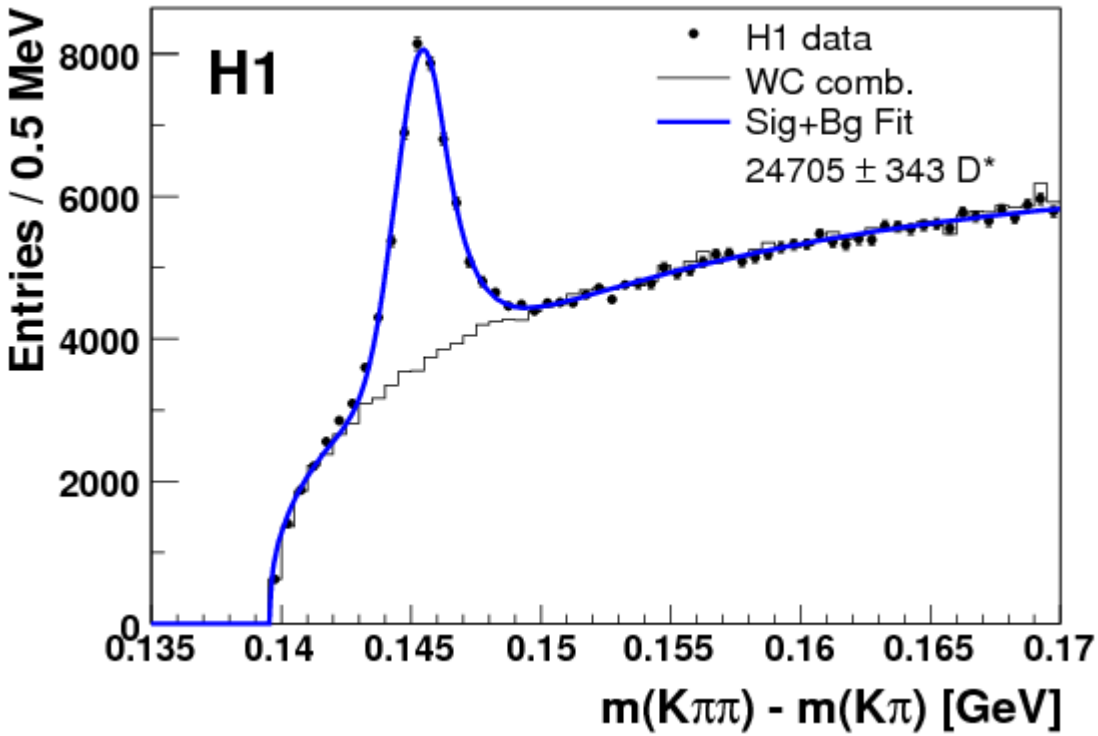
D* reconstruction with mass difference method: $\Delta m = \mathrm{m}(\mathrm{K}\pi\pi) - \mathrm{m}(\mathrm{K}\pi)$

Background reduction with dE/dx cut on kaon.

DIS Sample (full HERAII): total $\mathscr{L} = 348\ \mathrm{pb}^{-1}$

Event Selection and Signal Extraction

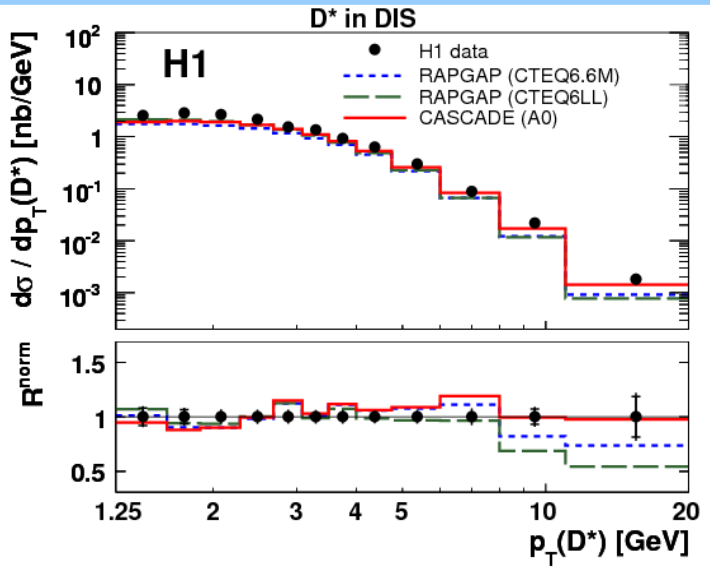
Full HERAII data set: ~24705 D* mesons (~10xHERAI statistic)

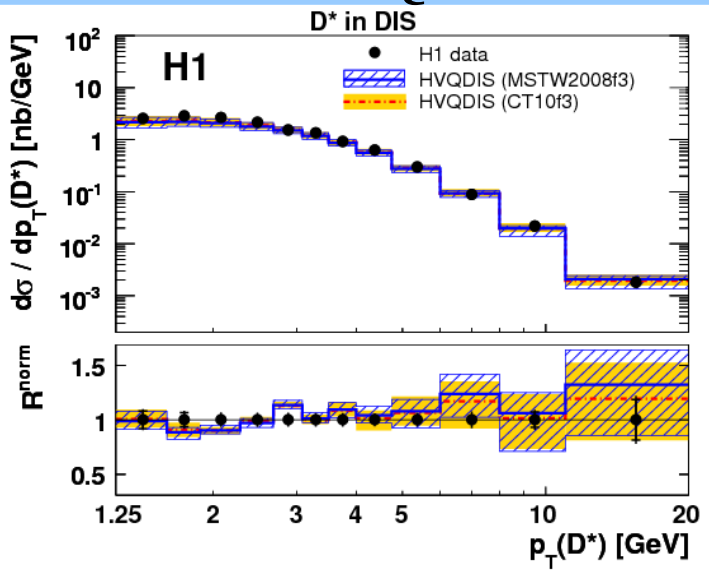


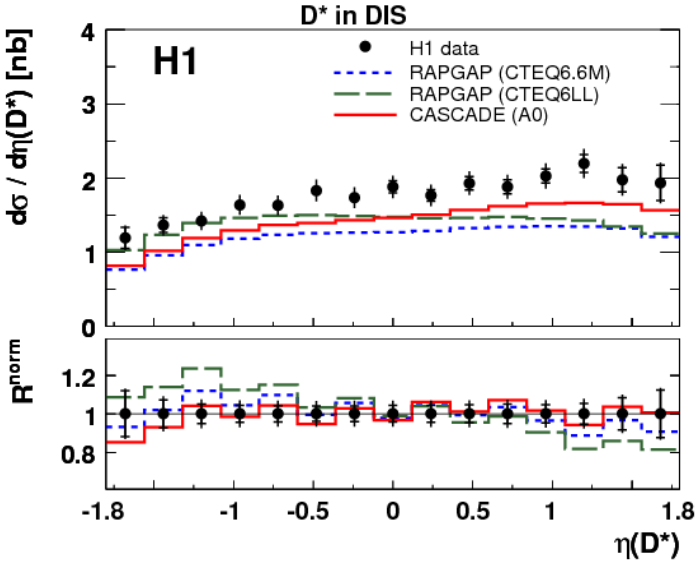
Cross section:

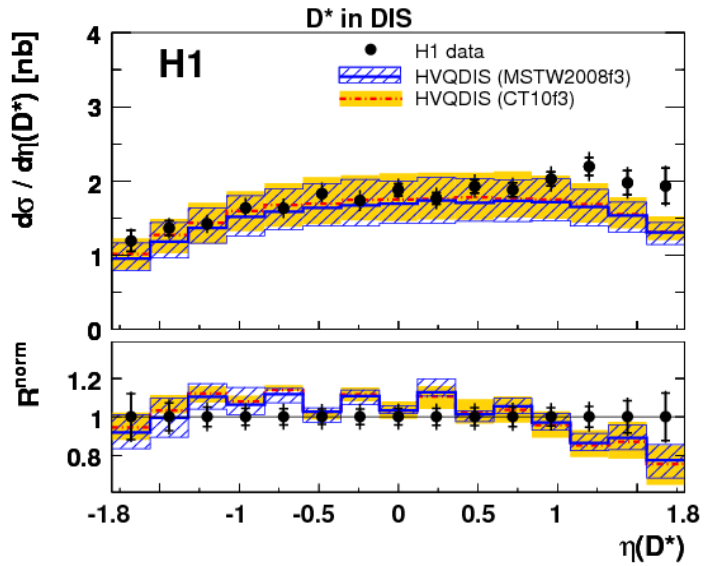
- Born-level cross sections by correcting for radiative effects.
- correction for detector effects (efficiency, migrations) with regularized matrix unfolding
- total systematic uncertainty *7.6%*
  (largest unc.: track efficiency with 4.1%)

Cross Sections (Kinematic Variables of D* Meson)
LO-MC and HVQDIS









Comparison of shape with normalized ratio:

$$R^{\mathrm{norm}} = \frac{1/\sigma^{\mathrm{theo}}_{\mathrm{vis}} \cdot \mathrm{d}\sigma^{\mathrm{theo}}/\mathrm{d}Y}{1/\sigma^{\mathrm{data}}_{\mathrm{vis}} \cdot \mathrm{d}\sigma^{\mathrm{data}}/\mathrm{d}Y}$$

->normalization unc. cancel out

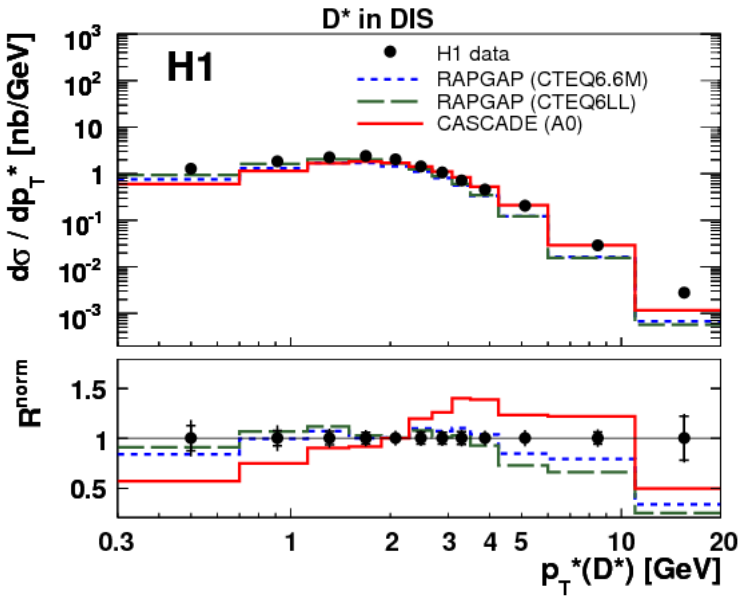
-p_T(D*): Reasonably well described

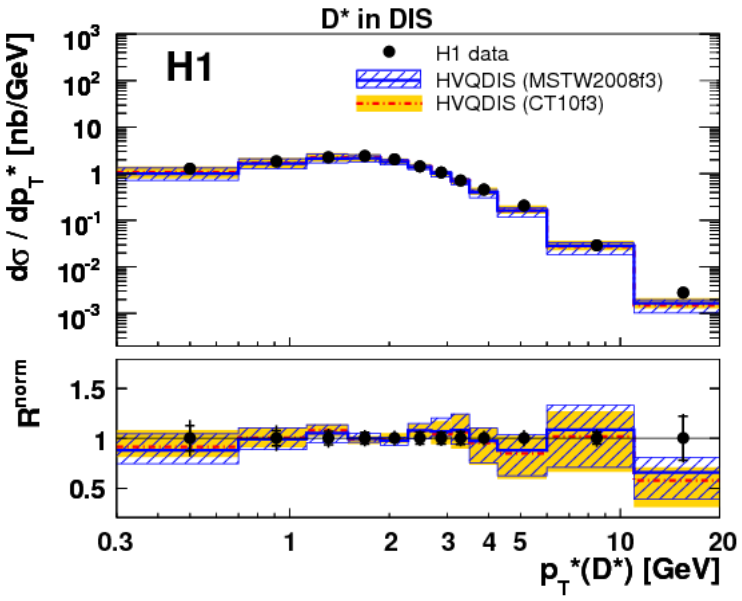
-η(D*): well described by CASCADE, HVQDIS.

RAPGAP(CTEQ6.6M) better as RAPGAP(CTEQ6LL)

Measurement covers 50% of total charm production phase space!

Cross Sections $p_T^*(D^*)$, $z(D^*)$



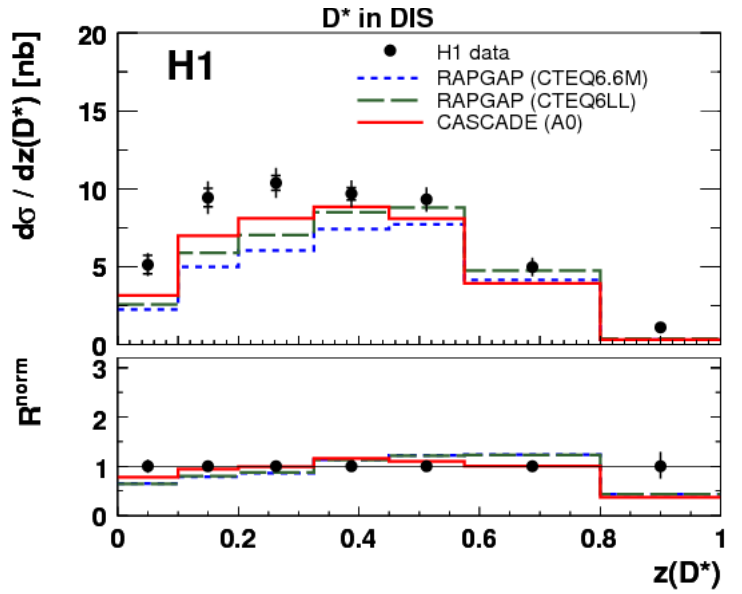


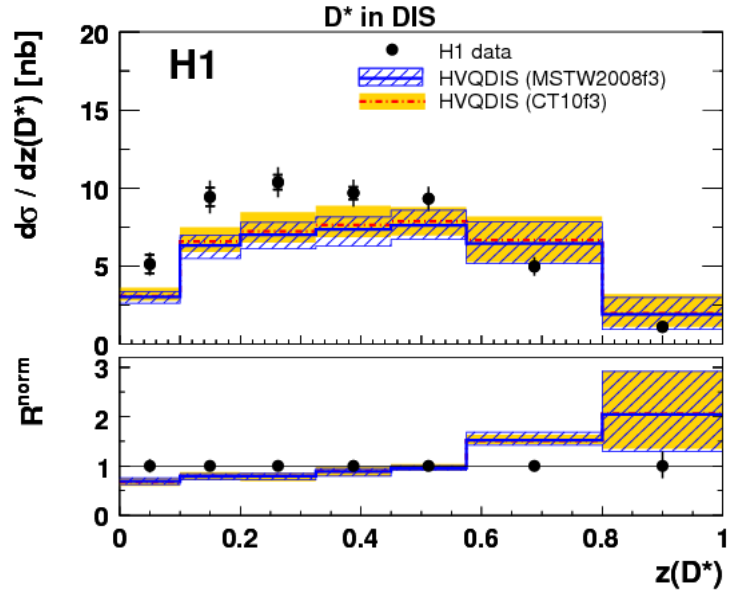
-$p_T^*(D^*)$:

CASCADE different shape,

RAPGAP too steep at large $p_T^*(D^*)$

HVQDIS good agreement

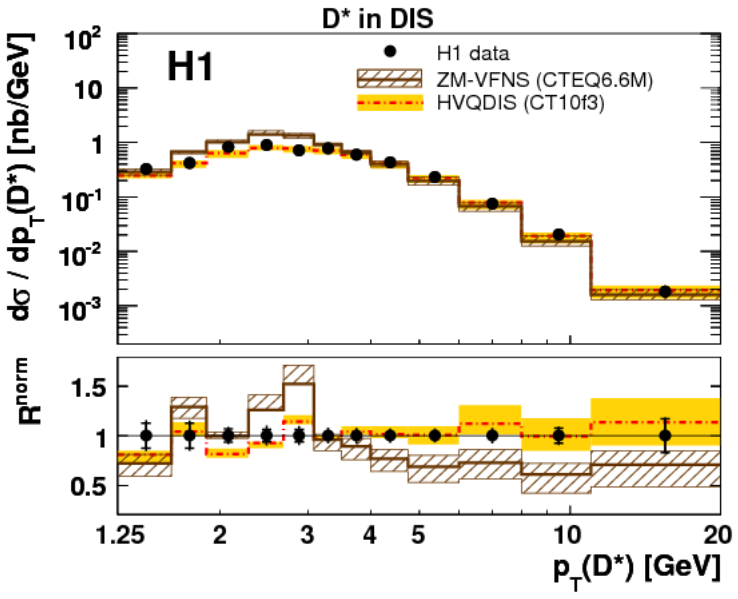


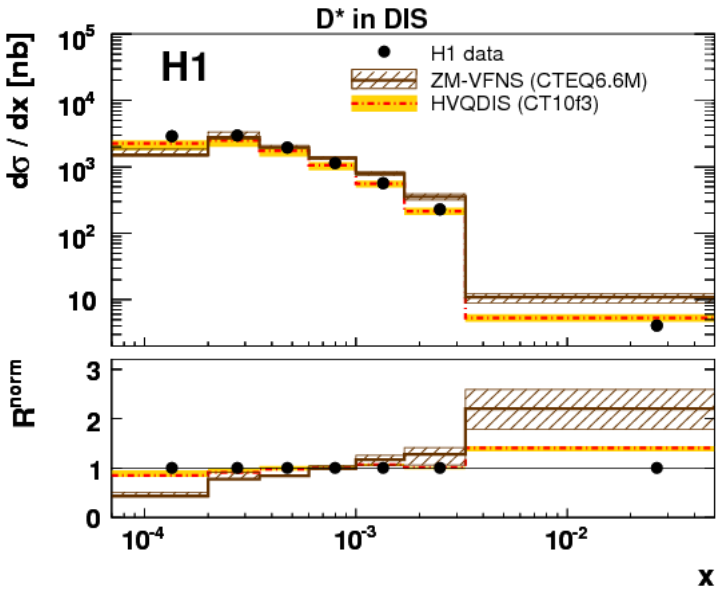


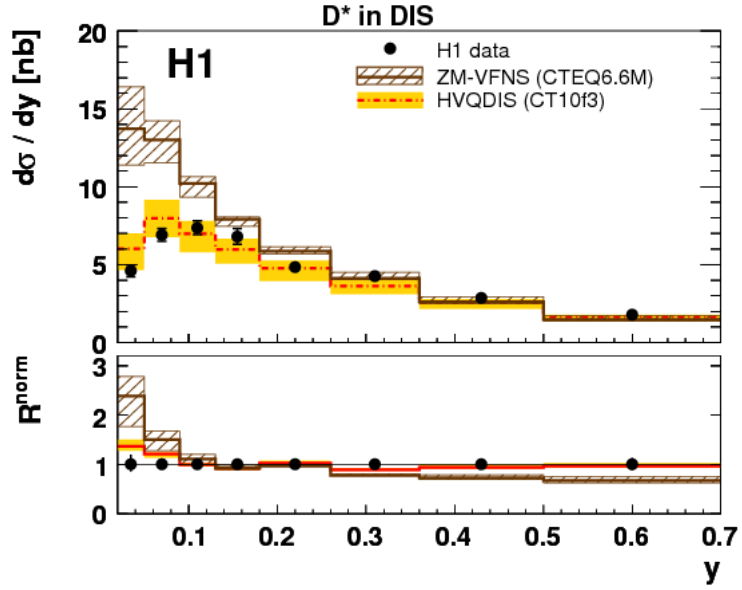
-$z(D^*)$:

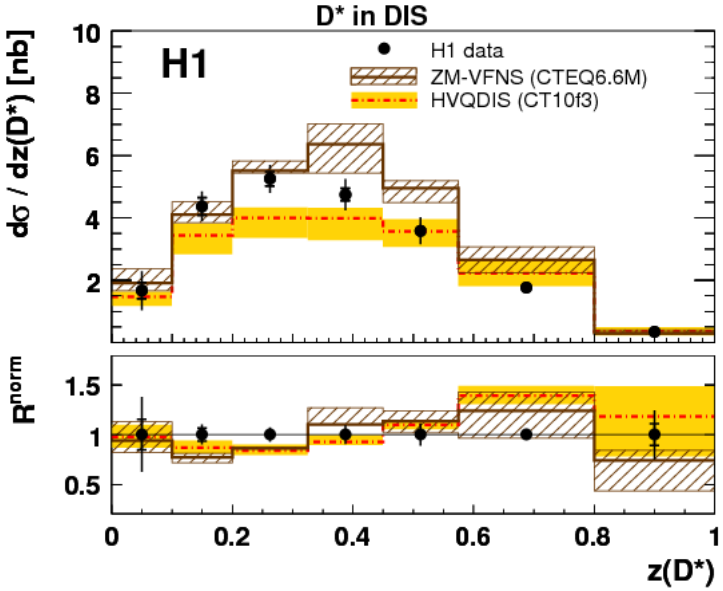
not described

Cross Sections compared to ZM-VFNS









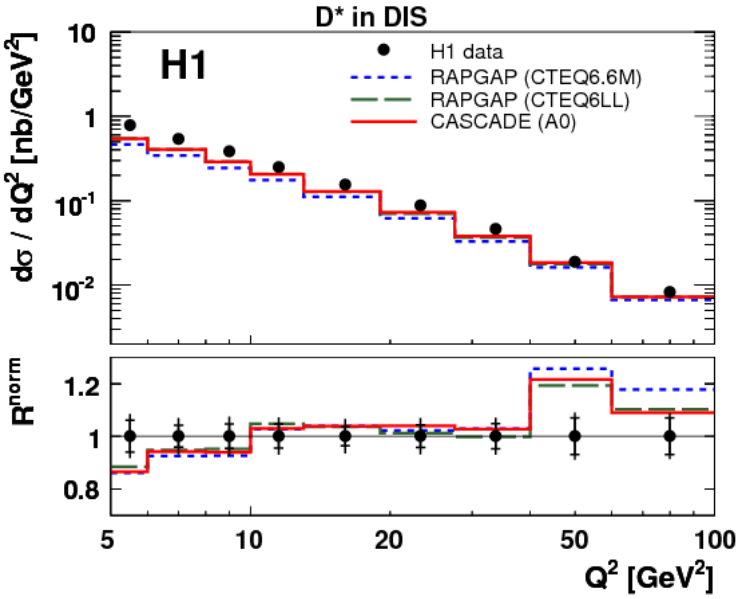
Expected that ZM calculation only valid for sufficiently large $p_T^*(D^*)$:

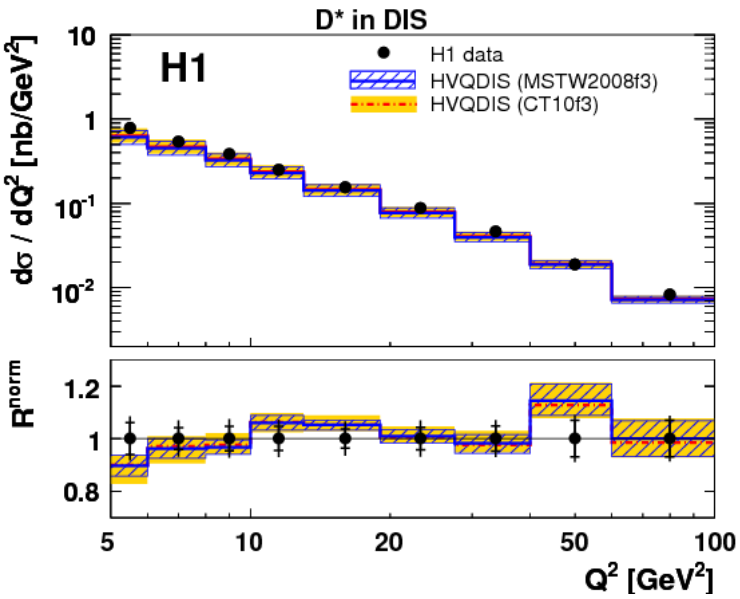
→ additional cut $p_T^*(D^*) > 2$ GeV

Error band ZM-VFNS:
- only scale uncertainties

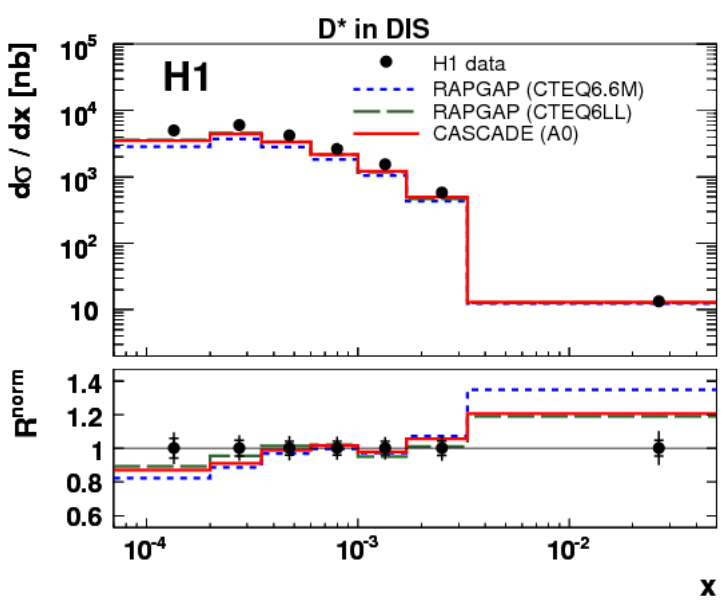
HVQDIS well, but data is not described by ZM-VFNS.
same observation at high Q^2!

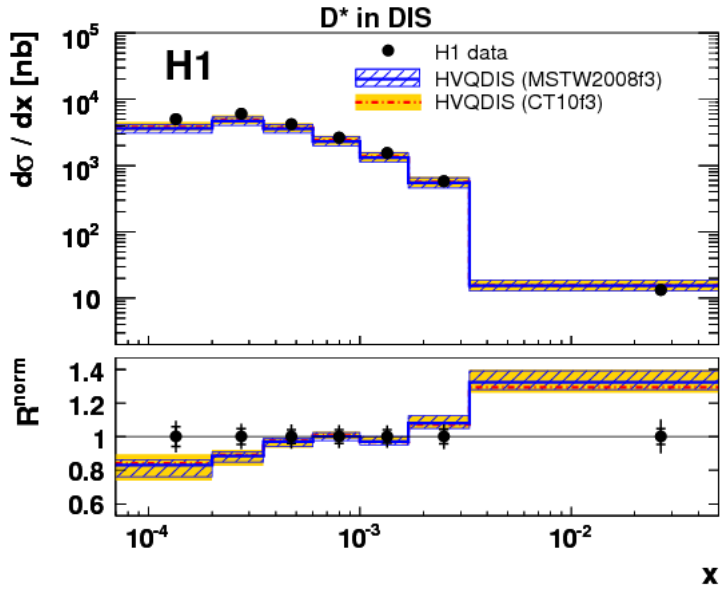
Cross Sections (Event Kinematics)
LO-MC and HVQDIS





- Q^2 : All predictions decrease less steep

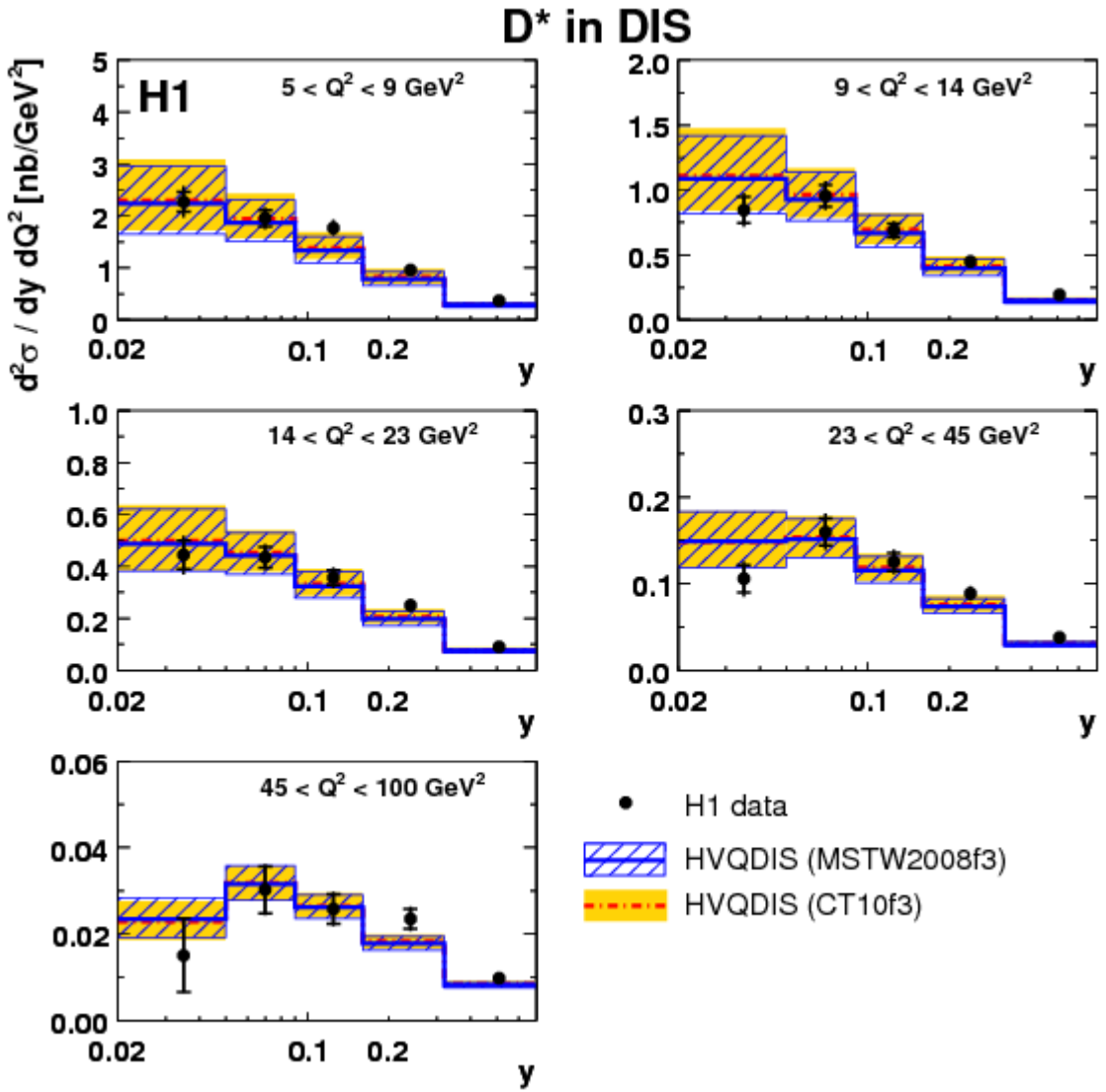




- x less steep dependence (more visible for NLO calculations)

- y well described by all

Double differential Cross Section y-Q^2



Well described by
All predictions!

Used as input for the determination of F_2^{cc}

Charm Contribution to the Proton Structure Function

Extraction of $F_2^{c\bar{c}}$:

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

Less than 4%

Measurement covers 50% of total charm production phase space.
->Extrapolation to full phase space:

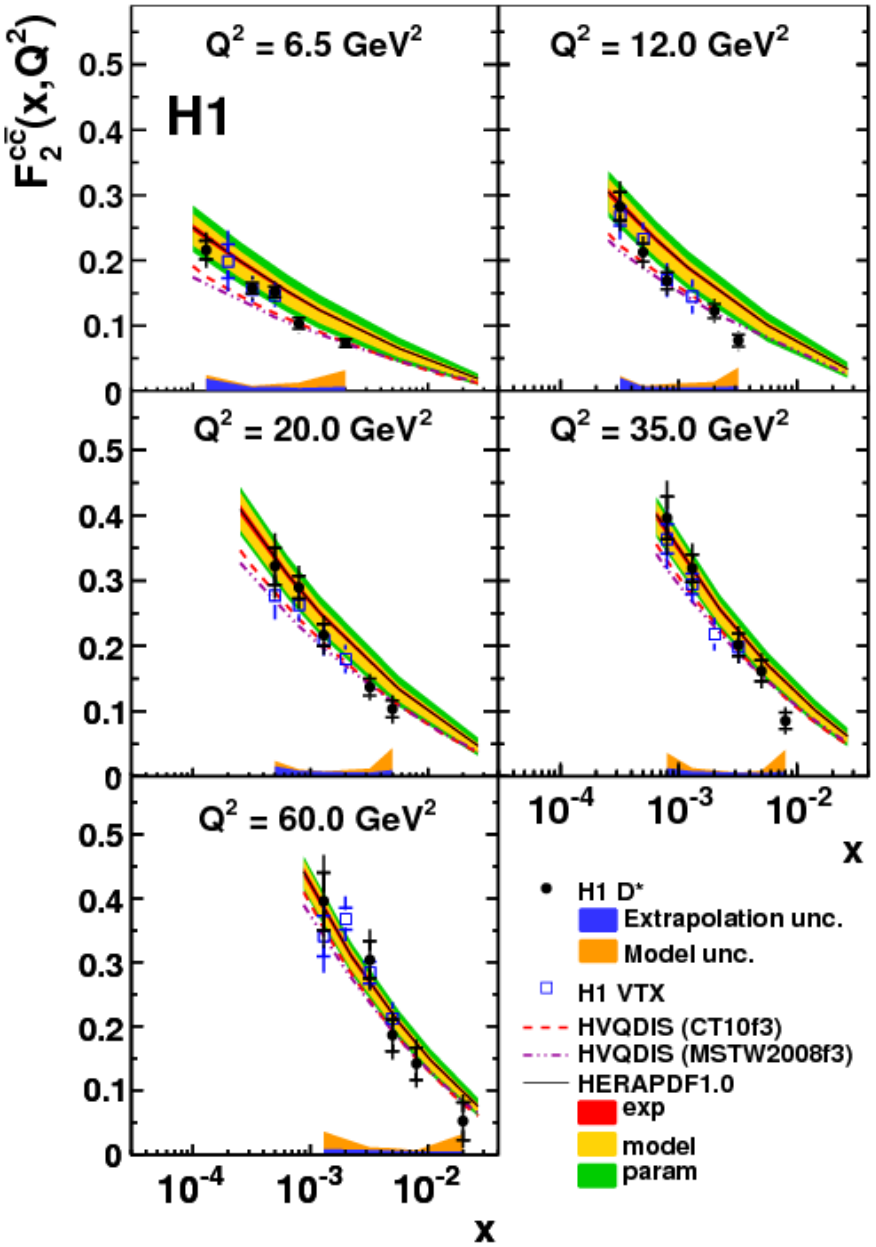
$$F_2^{c\bar{c}\,\mathrm{exp}}(\langle x\rangle,\langle Q^2\rangle) = \frac{\sigma_{\mathrm{vis}}^{\mathrm{exp}}(y,Q^2)}{\sigma_{\mathrm{vis}}^{\mathrm{theo}}(y,Q^2)} \cdot F_2^{c\bar{c}\,\mathrm{theo}}(\langle x\rangle,\langle Q^2\rangle)$$

Theoretical predictions: NLO DGLAP scheme (HVQDIS)

Uncertainties

- Extrapolation: estimated by varying theory parameters within HVQDIS (see Backup)
- Model: Extrapolation factors to full phase space model dependent:
  → done with HVQDIS and CASCADE

Charm Contribution to the Proton Structure Function



- Good agreement of D* measurement with H1 measurement using lifetime informations (**H1 VTX**), (Eur. Phys.J.C65:89-109,2010).

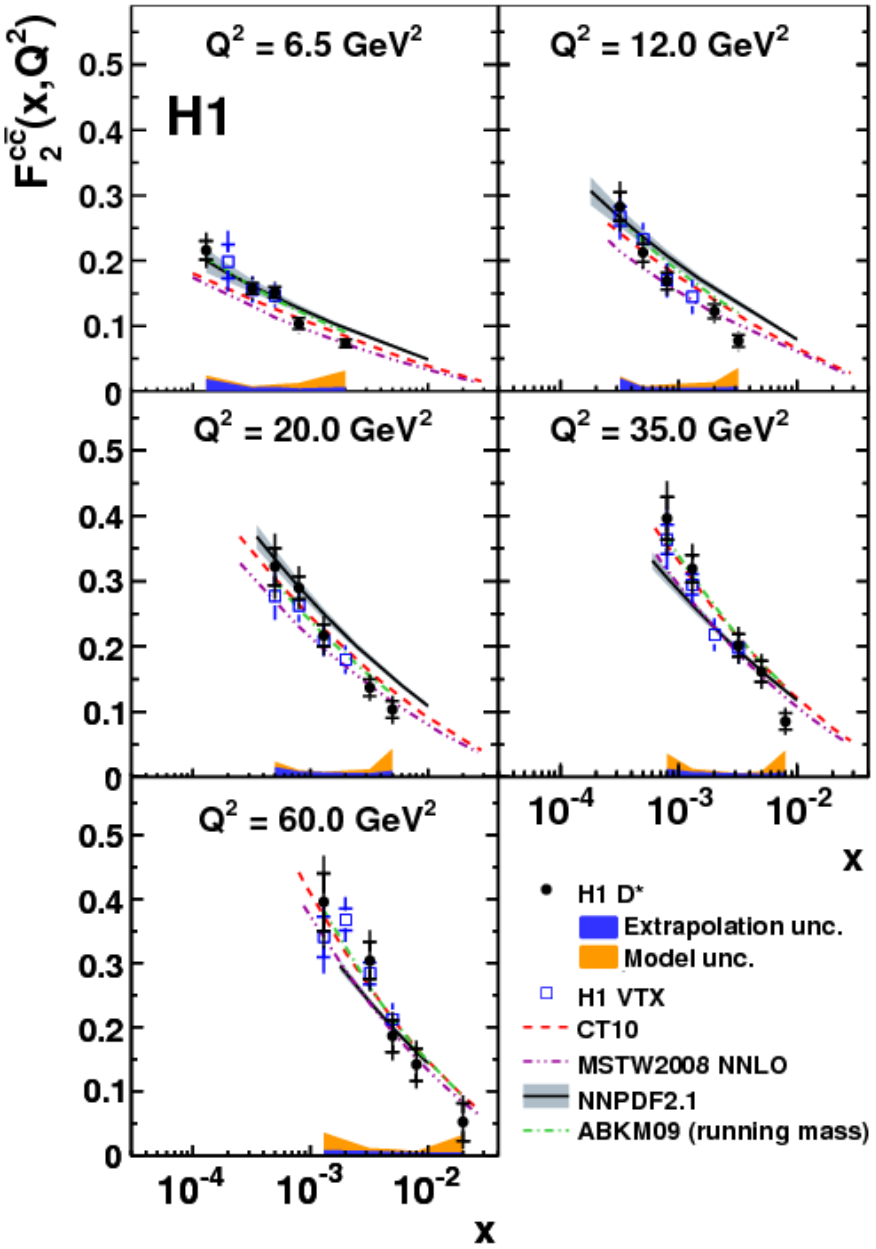
- comparison to FFNS NLO calc. with **CT10f3 and MSTW2008f3**: both reasonably well

- comparision to **HERAPDF1.0** (GMVFNS) (uncertainty dominated by m_c variation): general agreement

Predictions agree with $F_2^{c\bar{c}}$ measurement

→ gluon density from scaling violations of inclusive DIS cross section consistent with gluon density observed in charm production

Charm Contribution to the Proton Structure Function



- comparison to predictions from **Global PDF fits**:
  CT10, MSTW2008 NNLO, NNPDF2.1 (GMVFNS)
  ABKM09 (FFNS)

  in general: reasonably well
  at low Q^2 decrease less steep as data.

- experimental uncertainty comparable to spread of the predictions

Conclusion

Measurement of **D* meson cross sections** in DIS at HERA:

- increased phase space
- full HERAII statistics

- reasonably well described by **FFNS** calculations:
  MC simulations RAPGAP + CASCADE, NLO HVQDIS
- not described by **ZM-VFNS**

Charm contribution to proton $\mathbf{F_2^{c\bar{c}}}$:

- extrapolation to full phase space with HVQDIS and CASCADE
- results consistent with H1 measurement with lifetime information

- well described by NLO calculations

→ gluon density from scaling violations of incl. DIS consistent with gluon density in charm production

Backup

QCD Models and MC Simulation

RAPGAP		
Parameter name	Central value	Variation
Charm mass	$m_c = 1.5$ GeV	
Renormalisation scale	$\mu_r = \sqrt{Q^2 + 4m_c^2 + (p_T^*)^2}$	
Factorisation scale	$\mu_f = \sqrt{Q^2 + 4m_c^2 + (p_T^*)^2}$	
Fragmentation	$\alpha = 10.3$ for $\hat{s} < \hat{s}_{threshold}$ $\alpha = 4.4$ for $\hat{s} > \hat{s}_{threshold}$ $\hat{s}_{threshold} = 70$ GeV^2	$8.7 < \alpha < 12.2$ $3.9 < \alpha < 5.0$ $50 < \hat{s}_{threshold} < 90$ GeV^2
PDF	CTEQ6.6M (NLO)	CTEQ6LL (LO)

CASCADE		
Parameter name	Central value	Variation
Charm mass	$m_c = 1.5$ GeV	
Renormalisation scale	$\mu_{r,0} = \sqrt{Q^2 + 4m_c^2 + p_T^2}$	$1/2 < \mu_r/\mu_{r,0} < 2$
Factorisation scale	$\mu_{f,0} = \sqrt{\hat{s} + Q_T^2}$	$1/2 < \mu_f/\mu_{f,0} < 2$
Fragmentation	$\alpha = 8.4$ for $\hat{s} < \hat{s}_{threshold}$ $\alpha = 4.5$ for $\hat{s} > \hat{s}_{threshold}$ $\hat{s}_{threshold} = 70$ GeV^2	$7.3 < \alpha < 9.8$ $3.9 < \alpha < 5.1$ $50 < \hat{s}_{threshold} < 90$ GeV^2
PDF	A0	μ_r variation: A0-, A0+

HVQDIS		
Parameter name	Central value	Variation
Charm mass	$m_c = 1.5$ GeV	$1.3 < m_c < 1.7$ GeV
Renormalisation scale	$\mu_{r,0} = \sqrt{Q^2 + 4m_c^2}$	$1/2 < \mu_r/\mu_{r,0} < 2$
Factorisation scale	$\mu_{f,0} = \sqrt{Q^2 + 4m_c^2}$	$1/2 < \mu_f/\mu_{f,0} < 2$
Fragmentation	$\alpha = 6.1$ for $\hat{s} < \hat{s}_{threshold}$ $\alpha = 3.3$ for $\hat{s} > \hat{s}_{threshold}$ $\hat{s}_{threshold} = 70$ GeV^2	$5.3 < \alpha < 7.0$ $2.9 < \alpha < 3.7$ $50 < \hat{s}_{threshold} < 90$ GeV^2
PDF	CT10f3 (NLO)	MSTW2008f3 (NLO)
Fragmentation fraction	$f(c \to D^*) = 23.8 \pm 0.8\%$ [37]	

ZM-VFNS		
Parameter name	Central value	Variation
Charm mass	$m_c = 1.5$ GeV	
Renormalisation scale	$\mu_{r,0} = \sqrt{(Q^2 + (p_T^*)^2)/2}$	$1/2 < \mu_r/\mu_{r,0} < 2$
Factorisation scale	$\mu_{f,0} = \sqrt{(Q^2 + (p_T^*)^2)/2}$	$1/2 < \mu_f/\mu_{f,0} < 2$
Fragmentation	KKKS08 [39]	
PDF	CTEQ6.6M	

Extrapolation factors