

Measurement of Inclusive and Dijet D^* Meson Cross Sections in Photoproduction at HERA

Zlatka Staykova
for the H1 Collaboration

University of Antwerp,
Belgium

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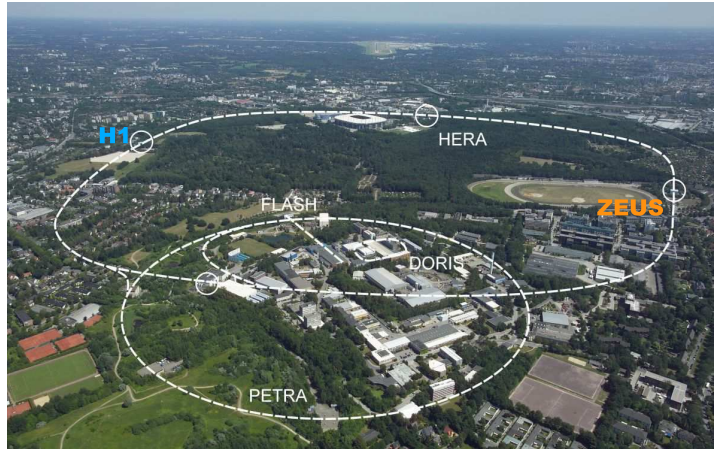


Outline

- ▶ HERA, H1 and ep scattering
- ▶ Heavy quark physics in photoproduction
- ▶ Results on the inclusive D^* cross sections
- ▶ Results on the dijet D^* cross sections

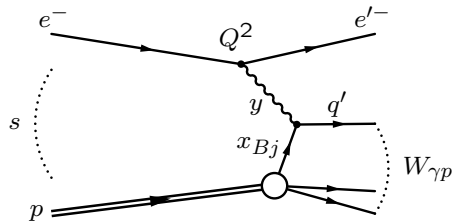
HERA

- ▶ 6.3km long with 15 years of data taking
- ▶ ep collisions at $\sqrt{s} \approx 320$ GeV
- ▶ H1 and ZEUS—multipurpose detectors
- ▶ 0.5 fb^{-1} each experiment



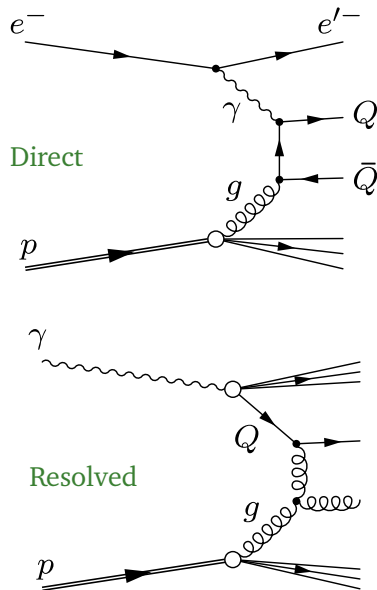
ep Scattering

- ▶ Invariants:
 - ★ $Q^2 \equiv -\gamma^2$ - photon virtuality
 - ★ The Bjorken variables: y and x_{Bj}
- ▶ $W_{\gamma p}^2 = (p + \gamma)^2$
- ▶ $Q^2 \lesssim m_p^2$ photoproduction, dominates the total ep cross section
- ▶ Only two of these invariants are independent



QCD and Heavy Quarks

- ▶ Heavy quarks are dominantly produced with Boson-gluon fusion
- ▶ QCD expansions usually performed in $\alpha_s(Q^2)$
- ▶ At vanishing Q^2 hard scales like high p_T jets and m_Q are used
 - ★ $m_{c/b} \gg \Lambda_{QCD}$ well above the pQCD threshold
 - ★ BGF \implies sensitivity to the gluon pdf in low x_g values \longrightarrow test parton evolution
 - ★ In γp there is significant contribution from resolved photons involving the photon structure itself
 - ★ Challenge for NLO– multiscales p_T, m_Q, m_T
- ▶ Further parton emission treated in terms of parton evolution
 - ★ DGLAP– k_t ordering
 - ★ CCFM– angular ordering



Monte Carlo Models and QCD predictions

▶ LO MC:

- ★ PYTHIA collinear factorisation using DGLAP evolution, CASCADE yielding CCFM evolution using k_T factorisation

▶ NLO calculations:

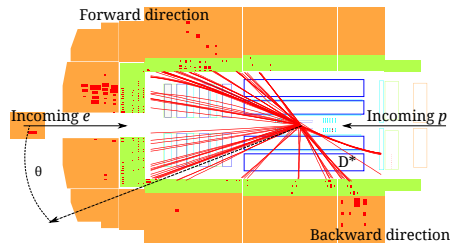
- ★ FMNR– collinear factorisation, massive heavy quarks, Peterson fragmentation
- ★ MC@NLO– NLO calculations as in FMNR matched with parton showers as in HERWIG
- ★ GMVFNS– collinear factorisation, KKKS fragmentation

$$m_T^2 = p_t^2 + m_c^2$$

generator	proton (u)pdfs	photon pdfs	scales
PYTHIA CASCADE	CTEQ 6L Set A0	GRV-G LO –	
FMNR MC@NLO GMVFNS	HERAPDF1.0	GRV-G HO GRV-G HO AFG04	$\mu_r = \mu_f/2 = m_T$ $\mu_r = \mu_f/2 = m_T$ $\mu_r = \mu_f = m_T$

Event Selection and Reconstruction

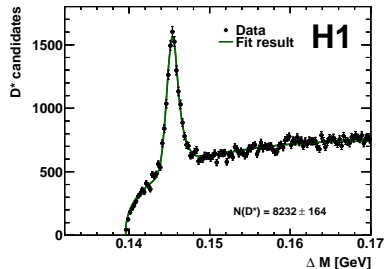
- ▶ H1, HERA II data, $\mathcal{L} = 93.4 \text{ pb}^{-1}$
- ▶ Untagged γp – $Q^2 < 2 \text{ GeV}$ in wider $W_{\gamma p}$ compared HERAI
 - ★ Event variables reconstructed from the four vectors of the final states
- ▶ The golden decay channel $D^* \rightarrow K\pi \rightarrow K\pi\pi$
 - ★ The event was triggered online by reconstructing the three charged particles
 - ★ The invariant mass $\Delta M = m(K\pi) - m(K\pi\pi)$ is formed and the number of particles is determined by a fit to that distribution
- ▶ 7 times larger statistics for the inclusive D^*
[Eur.Phys.J.C50:251-26]



$$\begin{array}{l} Q^2 < 2 \text{ GeV}^2 \\ 100 \text{ GeV} < W_{\gamma p} < 285 \text{ GeV} \\ \hline |\eta(D^*)| < 1.5 \\ p_t(D^*) > 1.8 \text{ GeV} \end{array}$$

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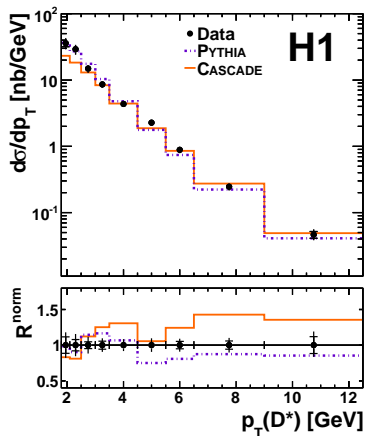
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Results

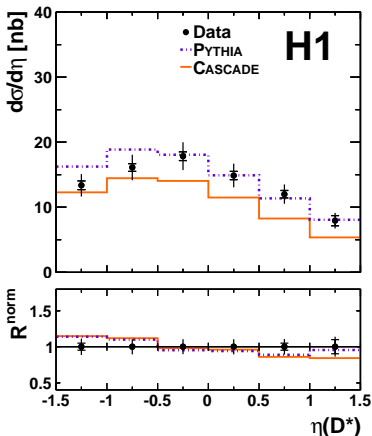
on Inclusive D^* in γp

[DESY 11-248]

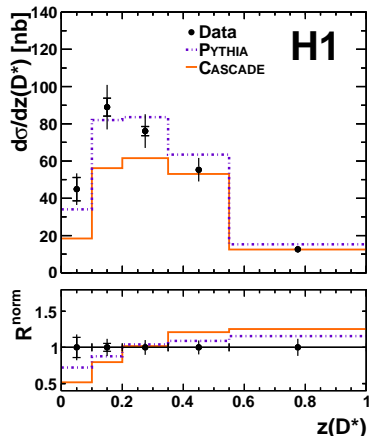
Kinematic Properties of the D^* Meson LO MC



- ▶ Shape comparison with $R = \sigma_{\text{data}}/\sigma_{\text{theory}}$

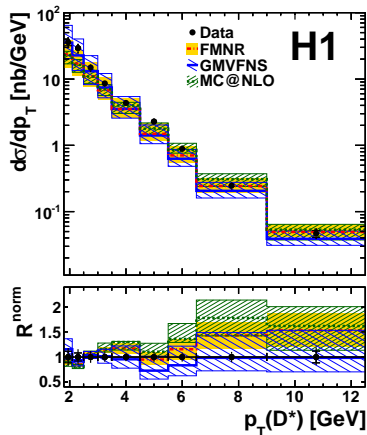


- ▶ Good description of the properties by PYTHIA

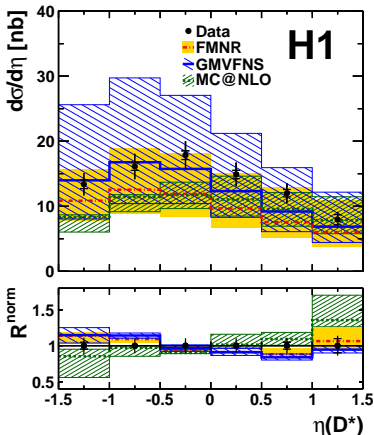


- ▶ Wrong Shape in $z(D^*)$ and p_t from CASCADE

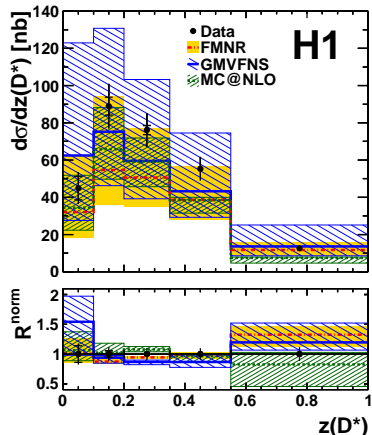
Kinematic Properties of the D^* Meson NLO



- ▶ Large theoretical uncertainties, dominated by variation of μ_r



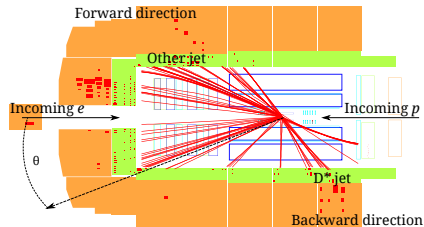
- ▶ Too low FMNR, MC@NLO at small p_t



- ▶ Reasonable $z(D^*)$

Jet Selection

- ▶ Jets are reconstructed using the k_T algorithm in the E recombination scheme
 - ★ The D^* meson is treated as a leading particle allowing to tag the D_{jet}^* . The D_{jet}^* is limited to the central $|\eta| < 1.5$ range by the tracking system
 - ★ The second hard parton in the event is identified with the highest p_t non- D^* jet– denoted as The Other jet
 - ★ Extended η range to cover the full calorimeter acceptance of H1 for the other jet
 - ▶ 4 larger samples compared to previous H1 publication
- [Eur.Phys.J.C50:251-26]



$$p_t(D^*) > 2.1 \text{ GeV}$$

$$p_t^{\text{jet}} > 3.5 \text{ GeV}$$

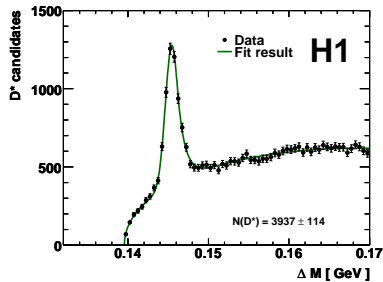
$$|\eta(D_{jet}^*)| < 1.5$$

$$-1.5 < \eta(\text{Other jet}) < 2.9$$

$$M_{jj} > 6 \text{ GeV}$$

Jet Selection

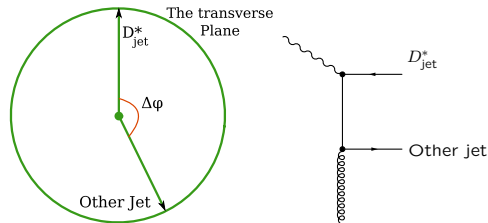
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$$\begin{array}{l} p_t(D^*) > 2.1 \text{ GeV} \\ p_t^{\text{jet}} > 3.5 \text{ GeV} \\ \hline |\eta(D_{jet}^*)| < 1.5 \\ -1.5 < \eta(\text{Other jet}) < 2.9 \\ M_{jj} > 6 \text{ GeV} \end{array}$$

Observables

- ▶ $\Delta\varphi = |\varphi_{D_{jet}^*} - \varphi_{Other\ jet}|$ sensitive to the k_t of the incoming gluon
- ▶ The longitudinal momentum fraction of the photon carried by the jets:
 - ★ $x_\gamma = \frac{\sum(E-p_z)_{jets}}{\sum(E-p_z)_{HFS}}$
 - ★ Small x_γ ($x_\gamma < 0.75$): Significant contribution from resolved photons
 - ★ Large x_γ ($x_\gamma \geq 0.75$): Direct photon enhanced sample

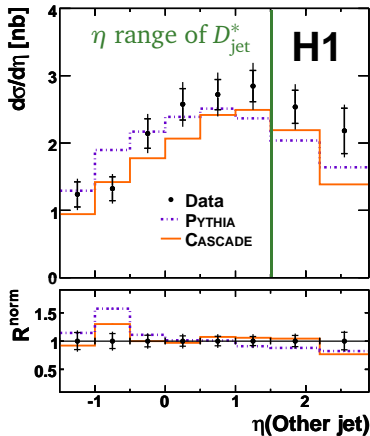
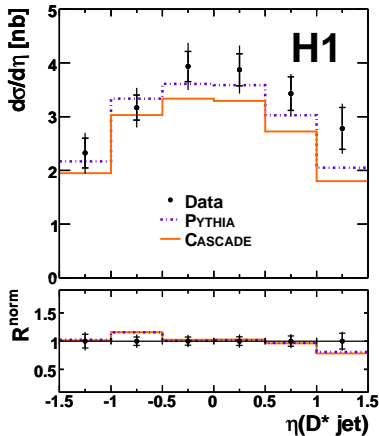


Results

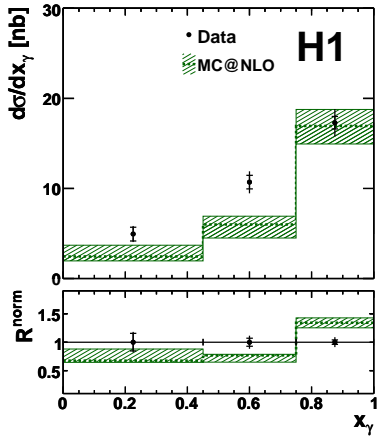
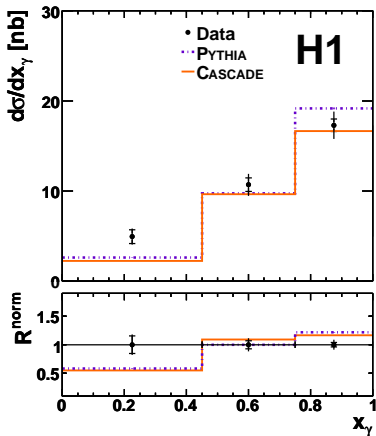
on Dijet D^* in γp

[DESY 11-248]

Pseudorapidity of the Jets



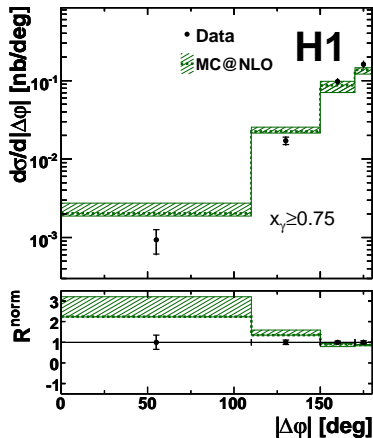
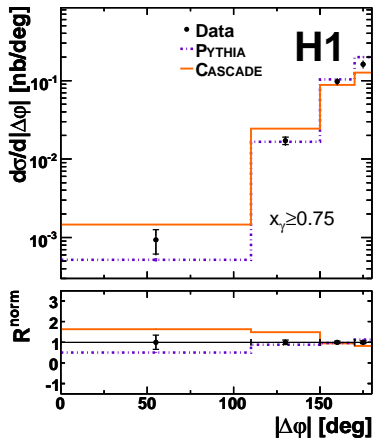
- ▶ Well described pseudorapidities
- ▶ The other jet is found more forward and in the region $|\eta| < 1.5$ the shapes for $\eta(D^*_{\text{jet}})$ and $\eta(\text{Other jet})$ are very different
- ▶ Indications that the other jet not always originates from charm quark

x_γ 

- ▶ $x_\gamma = \frac{\sum(E-p_z)_{jets}}{\sum(E-p_z)_{HFS}}$
- ▶ Lack of contribution from all models at small x_γ
- ▶ At small x_γ no significant difference between CCFM and DGLAP, wrong shapes by all three models

$\Delta\varphi$ in Large x_γ

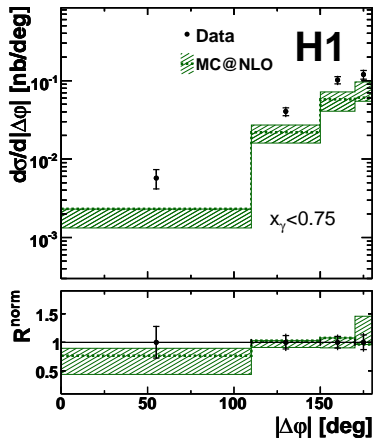
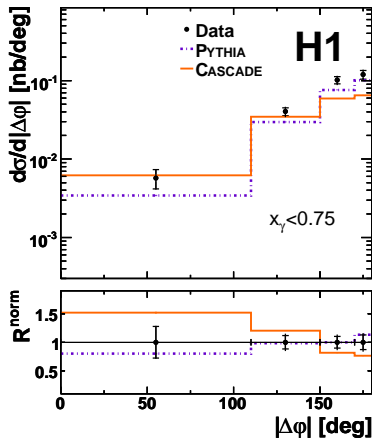
Direct photoproduction



- ▶ Sensitive to the parton evolution
- ▶ CASCADE underestimates the data at large $\Delta\varphi$ and overshoots the data at small $\Delta\varphi$
- ▶ PYTHIA provides good description of the distribution
- ▶ MC@NLO the size of the cross section is well reproduced but fails to describe the shape

$\Delta\varphi$ in small x_γ

Direct photoproduction



- ▶ Sensitive to the parton evolution and photon structure
- ▶ CASCADE gives wrong shape, but models properly the size of the cross section at small $\Delta\varphi$
- ▶ PYTHIA provides good description of the distribution
- ▶ MC@NLO predicts the shape of the distribution but is off normalisation

Conclusions

- ▶ Single and double differential cross sections were measured for inclusive and dijet photoproduction of D^* with improved statistics
- ▶ The data are significantly more precise than NLO QCD predictions

Inclusive D^* :

- ★ Good description of the data by PYTHIA
- ★ Too low cross section in p_t by CASCADE
- ★ Good shape by NLO calculations

Dijet D^* :

- ▶ Significant differences between the models and the data are seen in variables related to the detailed description of the final state
 - ★ Higher order parton radiation or non-vanishing virtuality of the incoming parton is needed in order to describe the data