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

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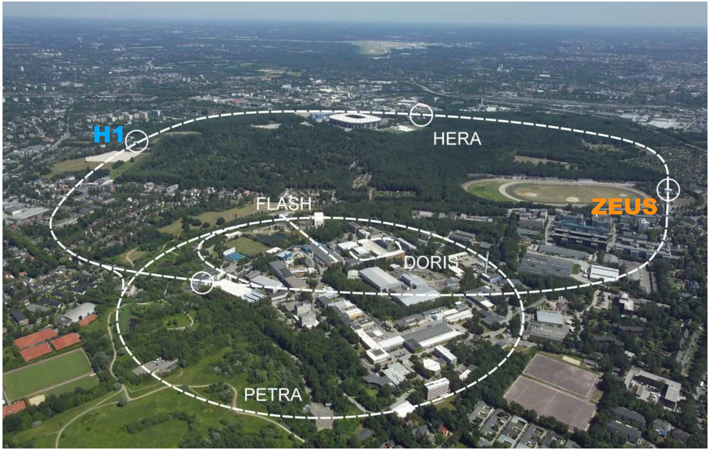
Outline

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

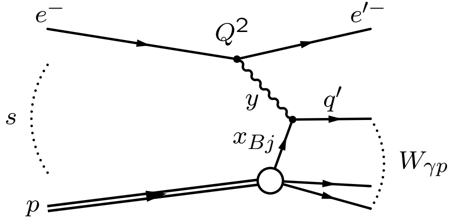
HERA

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



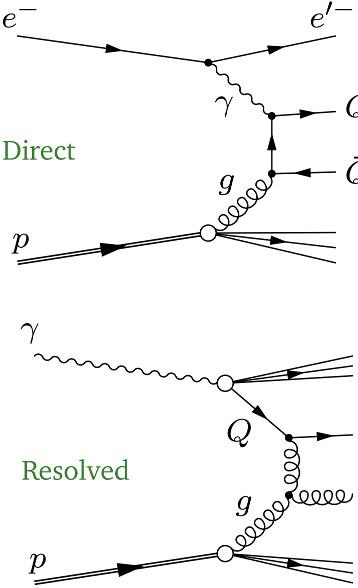
ep Scattering

- Invariants:
  - $Q^2 \equiv -\gamma^2$– photon virtuality
  - The Bjoerken variables: y and x_{Bj}
- $W^2_{\gamma p} = (p + \gamma)^2$
- $Q^2 \lesssim m_p$ 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 $\Longrightarrow$ 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

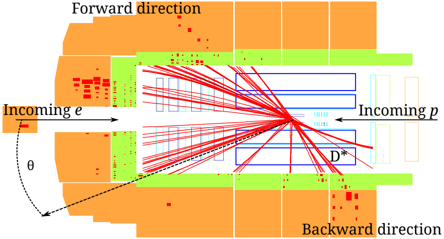
- LO MC:
  - ★ Pythia collinear factorisation using DGLAP evolution, Cascade yielding CCFM evolution using k_T factorisation
- NLO calculations:
  - ★ FMNR– collinear factorisation, massive heavy quarks, Peterson fragmentation
  - ★ MC@NLO– NLO calculations as in FMNR matched with parton showers as in Herwig
  - ★ GMVFNS– collinear factorisation, KKKS fragmentation

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

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

Event Selection and Reconstruction

- H1, HERA II data, $\mathcal{L} = 93.4\,\mathrm{pb}^{-1}$
- Untagged γp– $Q^2 < 2\,\mathrm{GeV}$ 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]



$Q^2 < 2\,\mathrm{GeV}^2$
$100\,\mathrm{GeV} < W_{\gamma p} < 285\,\mathrm{GeV}$

$|\eta(D^*)| < 1.5$
$p_t(D^*) > 1.8\,\mathrm{GeV}$

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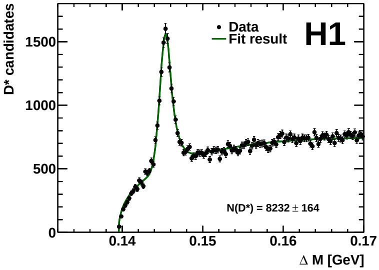

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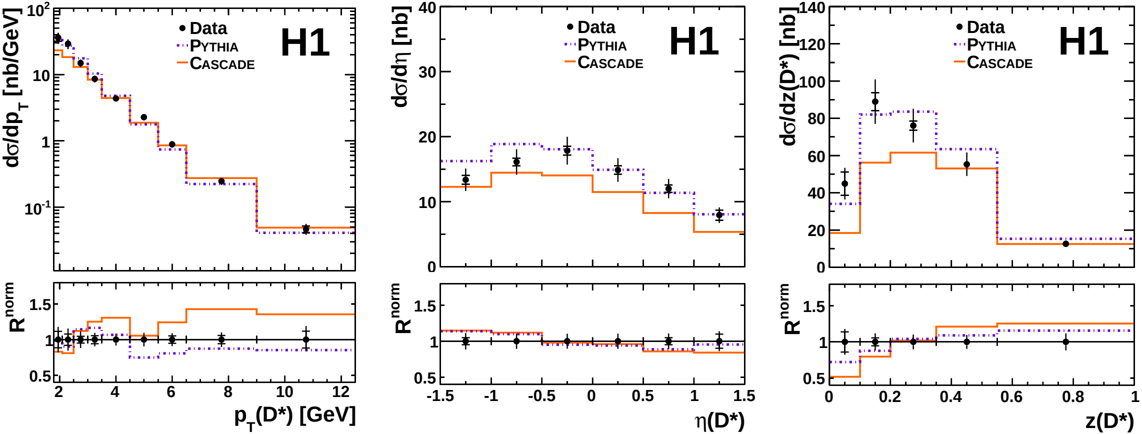
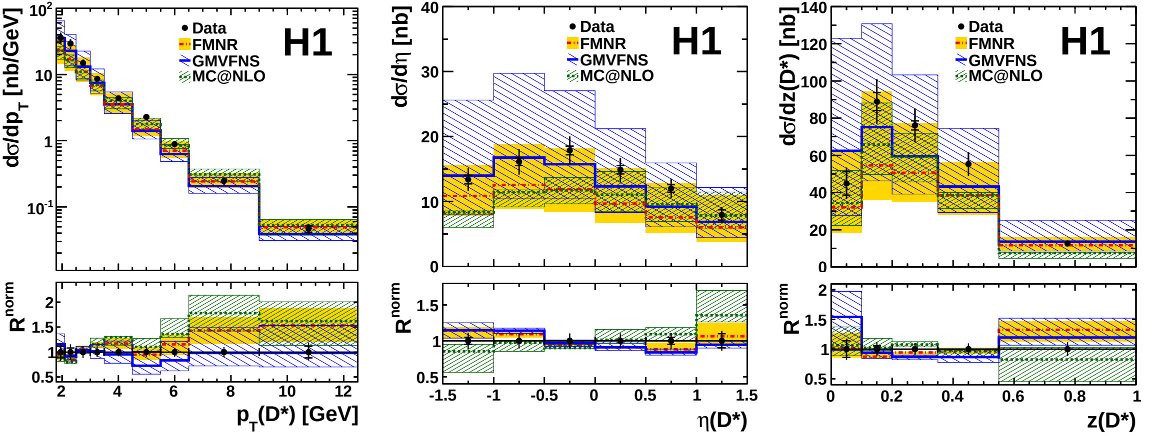
Results on Inclusive D^* in γp [DESY 11-248]

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

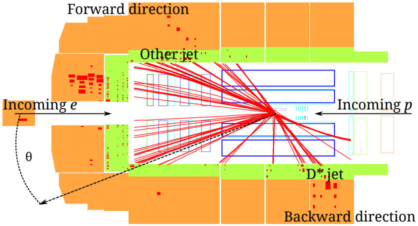
Kinematic Properties of the D^* Meson NLO



- 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]

$$p_t(D^*) > 2.1\,\text{GeV}$$
$$p_t^{\text{jet}} > 3.5\,\text{GeV}$$
$$|\eta(D^*_{\text{jet}})| < 1.5$$
$$-1.5 < \eta(\text{Other jet}) < 2.9$$
$$M_{jj} > 6\,\text{GeV}$$

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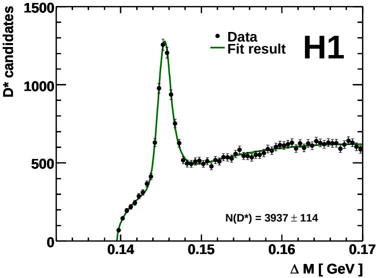

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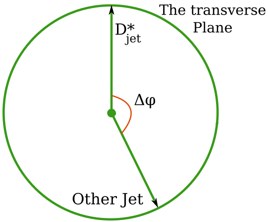
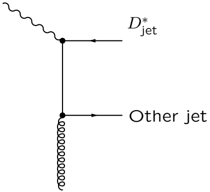
Observables

- $\Delta\varphi = |\varphi_{D^*_{jet}} - \varphi_{Other\ jet}|$ 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
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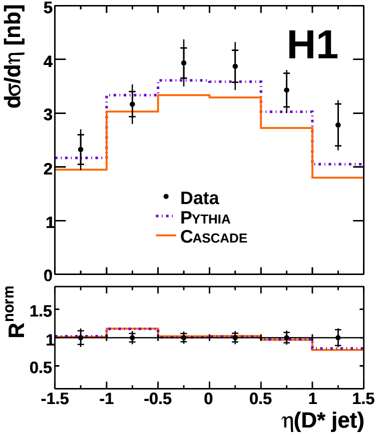
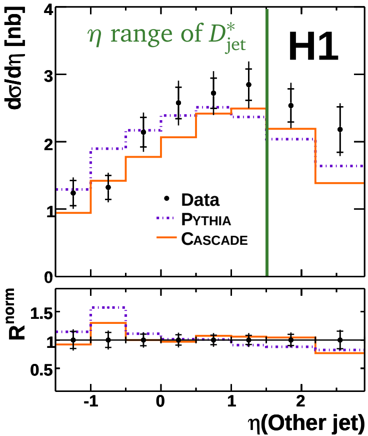
[DESY 11-248]

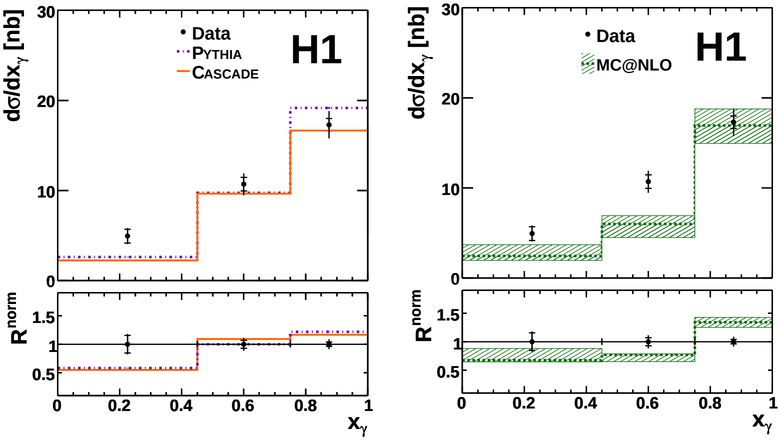
Pseudorapidity of the Jets





- 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

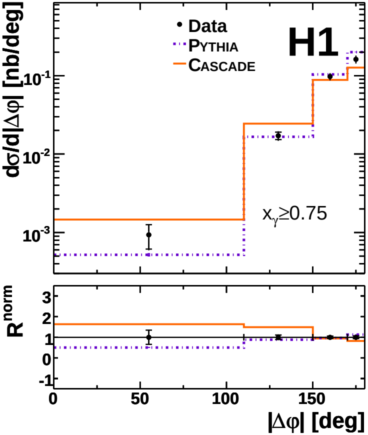
x_γ

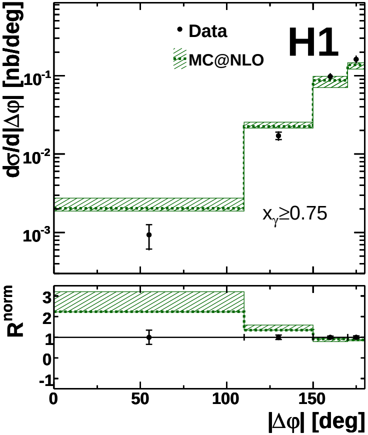


- $x_\gamma = \frac{\sum(E-p_z)_{jets}}{\sum(E-p_z)_{HFS}}$
- Lack of contribution from all models at small x_γ
- At small x_γ no significant difference between CCFM and DGLAP, wrong shapes by all three models

$\Delta\varphi$ in Large x_γ

Direct photoproduction

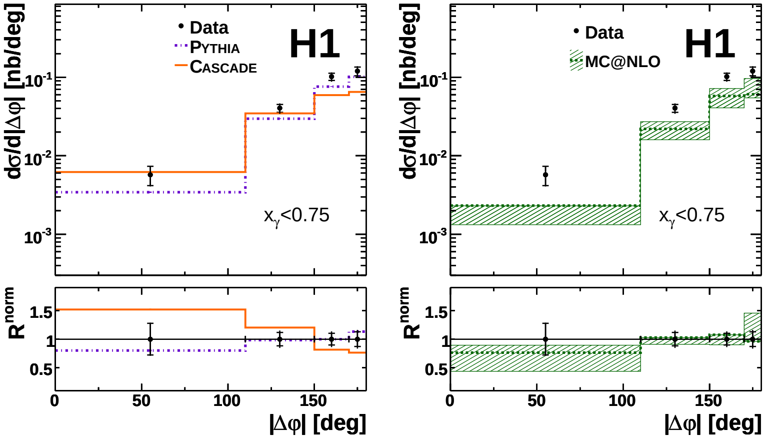




- Sensitive to the parton evolution
- CASCADE underestimates the data at large $\Delta\varphi$ and overshoots the data at small $\Delta\varphi$
- PYTHIA provides good description of the distribution
- MC@NLO the size of the cross section is well reproduced but fails to describe the shape

$\Delta\varphi$ 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