PROCEEDINGS OF SCIENCE

Photoproduction of D^* and Jets at H1

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Photoproduction events containing a charmed meson $D^{*\pm}$ and two jets were investigated with the H1 detector using the HERA II data sample. The D^* meson was reconstructed in the decay channel, $D^{*\pm} \to D^0\pi^\pm \to K^\mp\pi^\pm\pi^\pm$. Jets were reconstructed using the inclusive k_t algorithm and were selected if they have transverse momenta $p_t(\text{jet}) > 3.5\,\text{GeV}$. One of the jets was associated with the D^* meson itself, such that the jet originating from the parent charmed quark as the meson can be tagged. The phase space of the measurement is limited within central rapidity for the D^* meson and the D^*_{jet}, $|\eta| < 1.5$ while the second jet was measured within, $-1.5 < \eta < 2.9$. Single differential cross sections and double differential distributions were measured and compared to Leading Order Monte Carlo (MC) event generators, PYTHIA and CASCADE and with the Next–to–Leading order MC generator MC@NLO

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1. Introduction and Motivation

The dominant production process of charmed quarks in DIS is the boson gluon fusion process (BGF) (Fig. 1), where a gluon splits into quark anti–quark pair and then interacts with a virtual photon. Such charm production is highly sensitive to the gluon content of the proton. Moreover charm mass $m_c \simeq 1.5\,\text{GeV}$ provides the hard scale for perturbative calculations in the regime of photoproduction where the photon virtuality approaches zero. In summary charm quarks in photoproduction provide good testing ground for pQCD calculations.

Higher order processes are often approximated by parton showers, where the successive emitted partons from the proton side are ordered in a given kinematic quantity. Two major approaches are used, the DGLAP and the CCFM evolution equations. The basic difference between them is the quantity used for the ordering, in the case of DGLAP the transverse momentum of the partons is used, while in CCFM the emission angle with respect to the incoming gluon.

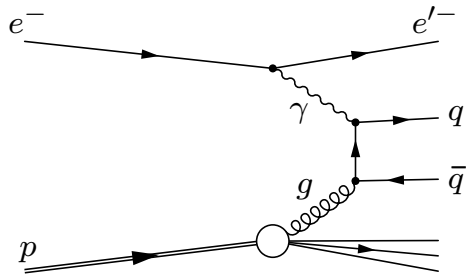

Figure 1: A Feynman diagram of the boson gluon fusion process.

In photoproduction the photon is quasi–real can split into partons. These events are called *resolved photoproduction* and are treated in terms of photon parton density functions (pdf) and evolution equations can be also applied to the photons. This is of particular need for the DGLAP based models [1]. The process when the photon interacts as a pointlike object is called *direct photoproduction*.

A previous measurement [2] of photoproduction of D^* mesons and two jets at H1, was found to be highly sensitive to the two different parton shower approaches. In the present measurement a larger data sample is used and the phase space was extended towards larger rapidity for the second jet.

Monte Carlo Models

The presented measurement was compared to two leading order Monte Carlo (MC) programs, PYTHIA [3] and CASCADE [4]. In PYTHIA the parton showers are implemented according to the DGLAP evolution equations. It generates also resolved photon processes. Two different modes of PYTHIA were used: in the first case the matrix elements were calculated explicitly for heavy quarks, and the final prediction is a mixture of two different samples, direct and resolved processes. For that case the SAS 2D LO photon pdfs were used as well as the CTEQ 6M NLO proton pdfs. In the second mode the generator calculates the matrix elements for massless quarks. In this case the photon pdfs were GRV-G LO and the CTEQ 6L LO proton pdfs were also used. The CASCADE MC generated the parton showers according to the CCFM evolution equation with the set A0 unintegrated proton pdfs. A next–to–leading order MC generator, (MC@NLO) [5] was also compared to the data. It is a full NLO matrix elements for heavy quark photoproduction matched with partons showers. The parton showers are implemented according to the DGLAP evolution equations, and were taken from the HERWIG MC program and the CTEQ 6.6 proton pdfs were used. The uncertainty of the calculation was estimated varying the factorisation and renormalisation scales.

2. Experimental Setup, Event Selection and Event Reconstruction

In this measurement the HERA II data sample collected with the H1 detector [6] was used, corresponding to an integrated luminosity of $\mathscr{L} = 93.4\,\mathrm{pb}^{-1}$. The measurement was performed in untagged photoproduction. The scattered electron escapes detection and the event kinematic variables were reconstructed using the hadronic final state (HFS). For the online triggering of the events the fast track trigger (FTT) [7] was used. Charged particles are reconstructed online and offline and combined into a D^* meson candidates using the mass hypothesis. The D^* was reconstructed in the channel: $D^{*\pm} \to D^0\pi^\pm \to K^\mp\pi^\pm\pi^\pm$. The D^* mesons were selected if they have transverse momentum $p_t > 2.1\,\mathrm{GeV}$ limited in the central rapidity range by the central tracking device $|\eta| < 1.5$. The jets were reconstructed with the inclusive k_t algorithm [8] in the laboratory frame in the energy recombination scheme. The D^* was treated as a leading particle, which means that the four vectors of the decay products of the meson were replaced by the four vector of the D^* itself in the HFS definition. Such, the D^*_{jet} could be identified. The second hardest jet in the event is denoted as the *other jet*. The jets were selected if they have transverse momentum of $p_t^{\mathrm{jet}} > 3.5\,\mathrm{GeV}$ in the central rapidity range for the D^*_{jet}, $|\eta(D^*_{\mathrm{jet}})| < 1.5$ to be consistent with the D^* selection. The other jet was measured in the range $-1.5 < \eta(\mathrm{Other\ jet}) < 2.9$. Finally a cut on the invariant mass of the jets $M_{\mathrm{jj}} > 6\,\mathrm{GeV}$ was applied.

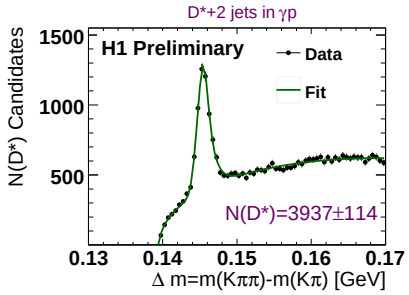

Figure 2: The mass difference $\Delta m = m(K\pi) - m(K\pi\pi_{slow})$

The number of signal events was determined from a fit to the D^* mass difference distribution $\Delta m = m(K\pi) - m(K\pi\pi)$, (Fig. 2). For the signal the asymmetric Crystal Ball [9] function was used. The fit was performed in each bin of the measurement. Within the selection about 4000 D^* mesons were found.

Various sources of systematic uncertainty were investigated leading to total systematic uncertainty of about 10%. The dominant sources are the luminosity measurement, track finding and the trigger efficiency uncertainties.

3. Results of the Measurement

The cross sections are measured in the phase space as summarised above. The results are presented in Fig.3 – Fig.5. The cross sections are represented by the black dots, where the inner error bar shows the systematic uncertainty and the outer error bar are the total uncertainty.

The kinematic quantities of the D^* and the jets (not shown here) are well reproduced by the MC generators. In Fig. 3 the differential cross section of D^* and two jets in photoproduction are shown as a function of the azimuthal angle difference between the two jets $\Delta\varphi$ (top left); the invariant mass of the remnant in the event M_X (top right); the average transverse momentum of the di–jet pair p_t^{jj} (bottom left) and the longitudinal momentum fraction of the photon carried by the jets x_γ (bottom right). Here, the shape of the azimuthal angle difference $\Delta\varphi$ is not well reproduced by three models. The back–to–back region $\Delta\varphi$ close to 180°, where the jets are balanced in p_t and contribution from

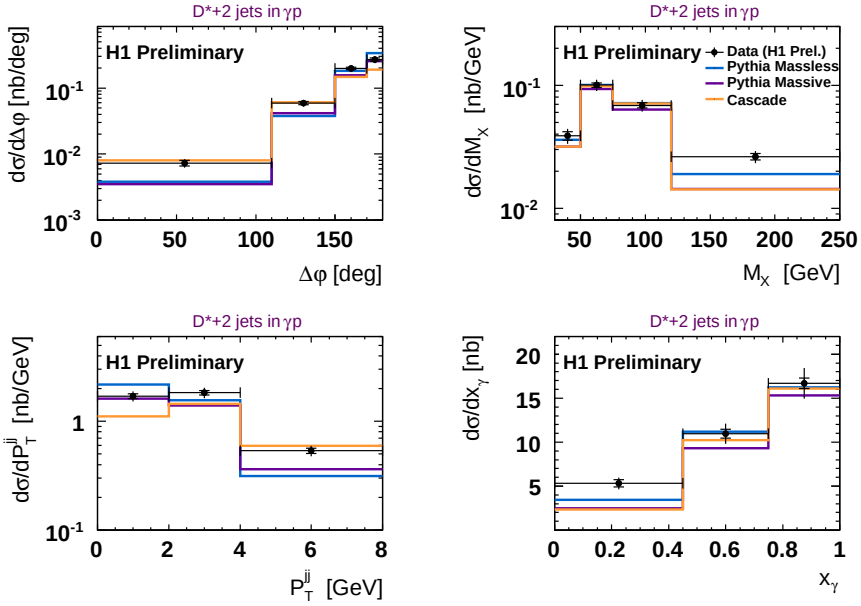

Figure 3: The differential cross sections for D^* and two jet production in photoproduction as a function of $\Delta\varphi$ between the jets, M_X, p_t^{jj} and x_γ.

higher order gluon radiation is not expected, is well modeled by PYTHIA massive. In the region towards small $\Delta\varphi$, further radiation is expected from momentum conservation, the data are well predicted by CASCADE. The same can be observed in the average transverse momentum of the jet pair p_t^{jj}. The invariant mass of the remnant $M_X^2 = (p+\gamma-(v_1+v_2))^2$, where $v_{1/2}$ are the four vectors of the two jets, is found to be well described by the models. The x_γ distribution is well described by the models with an exception of the lowest bin, where the contributions from events containing resolved photons is dominant.

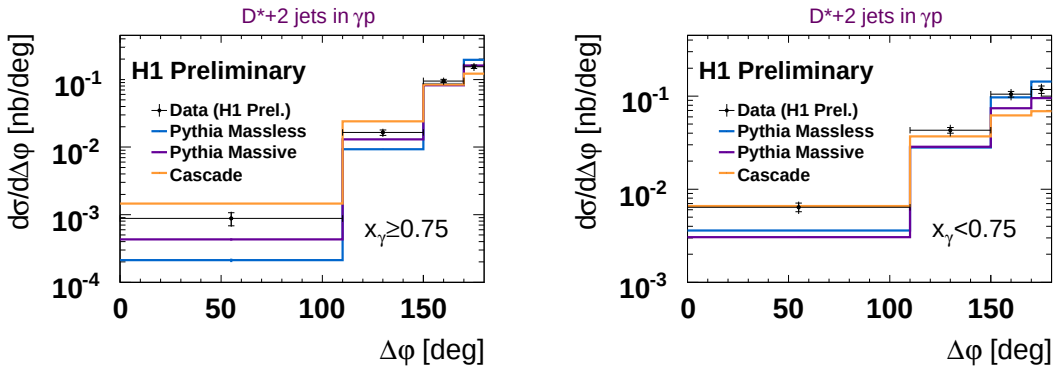

Figure 4: The $\Delta\varphi$ distribution for two bins of x_γ, compared to LO MC programs

The $\Delta\varphi$ distribution was also measured for two bins of x_γ (Fig. 4). For the direct photon case, $x_\gamma \geq 0.75$, within one sigma the distribution is fairly well modelled by CASCADE. It can be seen that at small $\Delta\varphi$ the model is slightly above the data. At the smallest $\Delta\varphi$ bin both PYTHIA

models are underestimating the data by a factor of 5. In the resolved case, $x_\gamma < 0.75$, CASCADE significantly underestimates the data in the back–to–back region, with a difference of factor of 4 while at the tail of the distribution towards small $\Delta\varphi$ the model describes the data. The predictions of PYTHIA for the smallest $\Delta\varphi$ bin is somewhat better than for the direct case. The data were also compared to MC@NLO. It was found that for the low $x_\gamma < 0.75$ (not shown here) region the predictions are below the data but for the direct photon $x_\gamma \geq 0.75$ case the shape is very well reproduced (see Fig. 5).

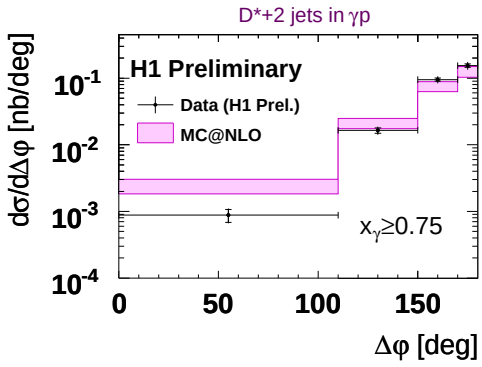

Figure 5: The $\Delta\varphi$ distribution for the high x_γ region compared to MC@NLO

4. Conclusions

Different pQCD and parton shower models can be tested by measuring charm cross sections with jets in photoproduction. A new measurement of D^* and two jets in photoproduction with the H1 detector was presented and differential cross sections and double differential distributions were measured with a larger data sample and in an extended phase space than a previous measurement by H1. Two new observables M_X and p_t^{jj} were introduced and measured. The measured cross sections were compared with predictions using different MC generators based on different parton shower models. It was found that the cross sections as a function of $\Delta\varphi$ shows very different shape for the data and the models.

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