A Measurement of the $D^{*\pm}$ Cross Section in Two-Photon Processes

TOPAZ Collaboration

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Abstract

We have measured the inclusive $D^{*\pm}$ production cross section in a two-photon collision at the TRISTAN $e^+e^-$ collider. The mean $\sqrt{s}$ of the collider was 57.16 GeV and the integrated luminosity was 150 $pb^{-1}$. The differential cross section $(d\sigma(D^{*\pm})/dP_T)$ was obtained in the $P_T$ range between 1.6 and 6.6 GeV and compared with theoretical predictions, such as those involving direct and resolved photon processes.

Hadron production in two-photon collisions is described by the vector-meson dominance model, the quark-parton model (direct process) [1], and the hard scattering of the hadronic constituents of almost-real photons (resolved photon process) [2,3,4,5], which has been observed by the previous experiments [6]. However, more detailed studies are necessary in order to understand these processes quantitatively. Heavy pair production processes are good probes, since the theoretical calculations are less ambiguous than for light quarks[6].

The previous measurements had been carried out at around $\sqrt{s} \sim 30 \text{ GeV}$ [7,8,9], and are consistent with a recent theoretical prediction [10]. At the TRISTAN energy ($\sqrt{s} \sim 60 \text{ GeV}$), the $c\bar{c}$ production cross section becomes sizable; we have obtained the largest statistics for this type of process. We carried out a measurement of the $D^{*\pm}$ production cross section at a $P_T$ greater than 1.6 GeV in two-photon collision events.

The detail concerning the TOPAZ detector can be found elsewhere [11]. The integrated luminosity of the event sample used in the analysis was 150 $pb^{-1}$. The mean $<\sqrt{s}>$ of the collider was 57.16 GeV. The trigger conditions are as follows: more than two tracks with $P_T > 0.3 \sim 0.7 \text{ GeV}$ and opening angle.

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> 45~70 degrees (depending on the beam condition); a neutral energy deposit in the barrel calorimeter be greater than 4 GeV; or that in the endcap calorimeters be greater than 10 GeV.

The selection criteria for two-photon events are as follows: the number of charged tracks be \( \geq 4 \); the total visible energy in the central part of the detector be between 4 and 25 GeV; the vector sum of the transverse momenta of the particles with respect to the beam axis (\( \Sigma \vec{P}_T \)) be less than 7.5 GeV; the sum of the charges be \( \leq 3 \); the event vertex be consistent with the beam crossing point; and no large energy clusters (\( E > 0.25E_{beam} \)) in the barrel calorimeter. In addition, we divided each event into two jets with respect to the plane perpendicular to the thrust axis, and the cosine of the angle between the two jets was required to be greater than -0.9. These restrictions were made in order to reduce beam-gas, and single-photon-exchange events. A total of 10788 events was selected.

The charged track selections were as follows: the closest approach to the event vertex be consistent within the measurement error; the number of degrees of freedom (DOF) in the track-fitting be \( \geq 3 \); and \( P_T \) be \( \geq 0.15 \) GeV.

The \( \gamma \) selections were: the cluster be detected by a barrel-type lead-glass calorimeter; the energy be \( \geq 0.2 \) GeV; and the cluster position be separated from any charged-track extrapolations. In addition, the \( e^+e^- \) pairs which were consistent with \( \gamma \) conversion at the inner vessel of the Time Projection Chamber (TPC) were reconstructed (1C-fit) and used as \( \gamma \) candidates.

In order to reconstruct charm quarks, we used the decay modes \( D^{\ast\pm} \rightarrow \pi^{\pm} D^0 (\bar{D}^0) \), followed by \( (D^0 (\bar{D}^0) \rightarrow K^\mp \pi^\mp X (X)) \). From now on, any mention of decays includes the charge conjugation modes, for simplicity. For \( D^0 \) decays, the decay modes \( D^0 \rightarrow K^- \pi^+, K^- \pi^+ \rho^0, K^- \pi^+ \pi^0 (K^+ \pi^+, K^- \rho^0, K^*0 \pi^0) \), and \( K^- \pi^+ \pi^0 \pi^0 \) were reconstructed by using kinematical constraint fits (1-3C). The cuts on \( \chi^2 \) were required to be greater than the 5% confidence level (CL). These decay modes were selected because they have relatively high acceptances, considering the branching fractions and detector acceptances. For more than two-body decay modes, we applied a \( dE/dx \) cut in selecting \( K^- \); for a two-body decay, a sufficient \( S/N \) was obtained without this cut. The cuts on the vector meson masses were carried out according to the detector resolution and their intrinsic decay widths. In the case of vector-plus-pseudo-scalar decay, we applied cut on the angle of the decay product of the vector meson (\( \theta_{VP} \)) in its center-of-mass frame with respect to the vector meson line of flight, i.e., |\( \cos \theta_{VP} \)| > 0.5.

The \( D^\ast \)'s were reconstructed with those \( D^0 \) candidates mentioned above while combining \( \pi^\pm \)'s (soft-pions from hereafter) with momenta less than 0.65 GeV. The energy fraction, \( z = E(D^{\ast\pm})/E_{beam} \), was required to be between 0.1 and 0.25. We then calculated the mass differences, i.e., \( dM = M(\pi^\pm D^0) - M(D^0) \). The \( dM \) distribution is plotted in Fig.1(a).

There were multi-\( D^0 \)-candidates for one soft-pion which gave similar \( dM \)'s. These occurred when one of the lowest momentum particles of the \( D^0 \) decay was misidentified. In these cases, each entry gave similar \( dM \) value. The differences of \( dM \) values for pairs sharing the same soft-pions in the same events were plotted in Fig. 3. The peak around zero caused an overestimate of the statistical significance of the signal. In order to cure them, we carried out a weighting method, i.e., when there was more than one \( D^0 \)-candidate for a given soft-pion, each entry in the \( dM \) histogram was weighted by the reciprocal of the number of candidates. By this procedure, we could avoid any overestimation of the statistical significance of the peak entry. This was checked using a Monte-Carlo simulation. The resulting \( dM \) distribution is shown in Fig. 3(b). The mean visible energy at the rest frame (WVIS) for the events containing the \( D^{\ast\pm} \) candidates were 5.3 GeV. In order to check the peak around the \( D^{\ast\pm} \) region, we carried out the wrong-sign combination such as \( D^0 \pi^- \) and etc. The results are plotted in Fig. 3(c), (d), and (e). There were no peak structures at all. The excess below the \( D^{\ast\pm} \) peak was explained by the energy loss at support structures of the inner field cage and the central membrane of the TPC, which were distributed inhomogeneously, whereas the correction for them were made only in average. Figs 3 show the mass-differences of two cases: (a) when the soft-pion passed near these supports, and (b) when it passed far from them. This happened because the soft-pions in the two photon events had extremely low momenta. We counted the entries of the higher \( dM \) peak as the \( D^{\ast\pm} \) yield in the experiment, and in...
Figure 1: Mass-difference ($dM = M(D^0\pi^\pm) - M(D^0)$) distributions: (a) dM distribution without the weighting; (b) after the weighting. The curve is obtained from a best-fit function described in the text; (c) dM distribution for wrong-sign soft-pion; (d) that for wrong-sign kaon; (e) that for wrong-sign soft-pion and wrong-sign kaon; and (f) background estimation from $e^+e^-\rightarrow\gamma\rightarrow q\bar{q}$ processes.
the Monte-Carlo we corrected the peak entries about -15% considering the amount of the materials and their solid angle from the interaction point. The error of this correction was considered to be 5% which was estimated from the $e^+e^-$ conversion pair yield in the two photon sample. Concerning the higher $dM$ fluctuation, we have no explanations other than statistical fluctuations. The fitting function was the sum of a Gaussian and the following function:

$$a(dM - M(\pi^\pm))b(1 - dM/c)^n,$$

where a, b, and c are free parameters and n is an average multiplicity of the event sample. The obtained $D^{*\pm}$ yield was $20.0 \pm 5.0$, where the $\chi^2$ of the fit was 31 with DOF=35. The peak position and its width obtained by this fitting were $147.4 \pm 0.2$, and $0.8 \pm 0.2$ MeV, where the detector simulation predicted $145.4$ and $1.6$ MeV, respectively. We considered that the shift of the peak position was caused by the inhomogeneous material distribution described above, whereas the energy loss correction was carried out assuming uniform material. The shift of the mass-difference peak quantitatively agreed with the expectation. The resolution difference was due to the overestimation of the material in front of the TPC in the simulation in the most probable energy-loss case. 85% of the soft-pions were considered to pass away from the support structures of the TPC. We tried $\chi^2$ and likelihood fitting and also tried polynomial background functions. The differences in the total $D^{*\pm}$ yields were within 10%. Thus we concluded that the systematic error of the fitting procedure was 10%. The yields for the four decay modes described before were $9.5 \pm 3.3$, $4.8 \pm 2.3$, $4.8 \pm 2.2$, and $0.9 \pm 0.9$, respectively.

The background from $e^+e^- \rightarrow \gamma \rightarrow q\bar{q}(\gamma)$ distributed smoothly in this $dM$ plot (height was about 1 count a bin as shown in Fig. 1-(f)). No peak structures were obtained by the Monte-Carlo simulation. We also checked the event vertex distribution in order to determine the contamination of the beam-gas background. There was a clear peak at the interaction point with no tails.

In order to compare the experimental data with the theoretical prediction, we chose $d\sigma(D^{*\pm})/dP_T$, instead of the total cross section, as had been reported \[\text{[8, 9, 10]}\]. Since the accepted $D^{*\pm}$ events were limited to the high $P_T$ region due to the detector acceptance. We were sensitive to those $D^{*\pm}s$ with transverse momenta ($P_T$) between 1.6 and 6.6 GeV. The lower limit was due to the detector acceptance and the higher due to statistics. An acceptance correction was carried out by using a lowest-order (Born approximation) direct-process Monte-Carlo simulation, in which an equivalent photon approximation was
Figure 3: Mass-differences of two cases: (a) when the soft-pion passed near the TPC support structures, and (b) when it passed far away from them.
Figure 4: $d\sigma(e^+e^- \to e^+e^- D^{*\pm}X)/dP_T$ versus $P_T$. The data points with error bars are the experimental data and the curves were obtained by Monte-Carlo simulations while assuming various processes. The hatched area is a prediction based on the direct process, the solid curve is based on a combination of direct and resolved photon process by the GRV parametrization, the dotted one is based on the LAC1 parameterization. The vertical scales for the resolved photon process were normalized by the relative acceptance to the direct process, because of the acceptance difference described in the text.
factor.

Corrections of order $\alpha_s$ were carried out according to the procedure in Ref. [19]. Since string fragmentation includes a parton-shower-like effect, the next-to-leading-order correction in the $P_T$ spectrum is doubly counted. We used instead the $P_T$-independent correction to the direct process. The cross section of the direct process is increased by a factor of 1.31 uniformly, and that of the resolved photon process is corrected by a $P_T$ dependent function, due to the presence of the process $\gamma q \rightarrow c\bar{c}q$ (a part of this is absorbed in the gluon density function in the resolved photon). The $P_T$ dependent factors were obtained by the following way: At first we derived the $P_T$ dependent ratios between the higher and the lowest order calculations for the direct and resolved photon processes; we then calculated the factors between those of the direct and resolved photon process; and those factors were normalized to fit to the total cross section of the higher order calculations for the resolved photon process. The resulted $P_T$ dependent correction were written as

$$0.50P_T^2 + 0.54,$$

where $P_T^e$ is a $P_T$ of charm quark. The charm quark mass ($m_c$) and the renormalization scale ($\mu$) were assumed to be $m_c=1.6$ GeV and $\mu = \sqrt{2m_c}$, respectively. The curves in Fig. 1 represent these predictions. The parametrization dependence for the resolved photon process appears in the lowest level. The parametrization dependence for the resolved photon process appears in the lowest order calculations for the direct and resolved photon processes; we then calculated the factors between those of the direct and resolved photon process; and those factors were normalized to fit to the total cross section of the higher order calculations for the resolved photon process. The resulted $P_T$ dependent correction were written as

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