FIRST MEASUREMENT OF $\Gamma(D^{**})$

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We have made the first measurement of the $D^{**}$ width using 9/fb of $e^+e^-$ data collected near the $\Upsilon(4S)$ resonance by the CLEO II.V detector. Our method uses advanced tracking techniques and a reconstruction method that takes advantage of the small vertical size of the CESR beam spot to measure the energy release distribution from the $D^{**} \rightarrow D^0\pi^+$ decay. Our preliminary result is $\Gamma(D^{**}) = 96 \pm 4$ (Statistical) $\pm 22$ (Systematic) keV.

A measurement of $\Gamma(D^{**})$ opens an important window on the non-perturbative strong physics involving heavy quarks. The basic framework of the theory is well understood, however, there is still much speculation - predictions for the width range from 15 keV to 150 keV. We know the $D^{**}$ width is dominated by strong decays, since the measured magnetic-dipole transition rate is small, $Br(D^{**} \rightarrow D^+\gamma) = 1.68 \pm 0.45\%$, and can be neglected to the first order. The level splitting in the $B$ sector is not large enough to allow real strong transitions. Therefore, a measurement of the $D^{**}$ width gives unique information about the strong coupling constant in heavy-light systems, $g_{D^+D^0\pi}$ or $g$.

Prior to this measurement, the $D^{**}$ width was limited to be less than 131 keV at the 90% confidence level by the ACCMOR collaboration. The limit was based on 110 signal events reconstructed in two $D^0$ decay channels with a background of 15% of the signal. This contribution describes a measurement of the $D^{**}$ width with the CLEO II.V detector where the signal, in excess of 11,500 events, is reconstructed through a single, well-measured sequence, $D^{**} \rightarrow \pi_{\text{slow}}D^0$, $D^0 \rightarrow K^-\pi^+$. Consideration of charge conjugated modes are implied throughout this paper. The level of background under the signal is less than 3% in our loosest selection.

The CLEO detector has been described in detail elsewhere. All of the data used in this analysis are taken with the detector in its II.V configuration. The data were taken in symmetric $e^+e^-$ collisions at a center of mass energy around 10 GeV with an integrated luminosity of 9.0/fb provided by the Cornell Electron-positron Storage Ring (CESR). The nominal sample follows the selection of $D^{**} \rightarrow \pi_{\text{slow}}D^0 \rightarrow \pi_{\text{slow}}K^-\pi^+$ candidates used in our $D^0-D^0$ mixing analysis.

Our reconstruction method takes advantage of the small CESR beam spot and the kinematics and topology of the $D^{**} \rightarrow \pi_{\text{slow}}D^0 \rightarrow \pi_{\text{slow}}K^-\pi^+$ decay chain. The $K^-$ and $\pi^+$ are required to form a common vertex. The resultant $D^0$ candidate momentum vector is then projected back to the CESR luminous region to determine the $D^0$ production point. The CESR luminous region has a Gaussian width $\sim 10 \mu$m vertically and $\sim 300 \mu$m horizontally. This procedure determines an accurate $D^0$ production point. Then the $\pi_{\text{slow}}$ track is re-fit constraining its
The observed width of $Q$ is negligible, $\Gamma(D^0) \ll \Gamma(D^{*+})$, implying that the observed width of $Q$ distribution is dominated by the shape given by the $D^{*+}$ intrinsic width and the tracking system response function. Thus we consider the pairs of $Q_i$ and $\sigma_{Q_i}$ for $D^{*+} \rightarrow \pi^+_\text{slow}D^0 \rightarrow \pi^+_\text{slow}K^-\pi^+$ where $\sigma_{Q_i}$ is given for each $i$-th candidate by propagating the tracking errors in the kinematic fit of the charged tracks. We perform an unbinned maximum likelihood fit to the $Q$ distribution, minimizing the likelihood function

$$L = 2(N_s + N_b) - 2 \sum_{i=1}^{N} \log[N_s \cdot S(Q_i, \sigma_{Q_i}; \Gamma_0, Q_0, f_{\text{mis}}, \sigma_{\text{mis}}) + N_b \cdot B(Q_i; b_{1,2,3})],$$

where $S$ and $B$ are respectively the signal and the background shapes, $N_s$ and $N_b$ number of signal and background events.

The shape of the underlying signal is assumed to be given by a P-wave Breit-Wigner, with central value of $Q$, $Q_0$. We considered a relativistic and a non-relativistic Breit-Wigners as a model of the underlying signal shape, and found negligible difference in the fit parameters. The width of the Breit-Wigner depends on $Q$ and is given by

$$\Gamma(Q) = \Gamma_0 \left( \frac{P}{P_0} \right)^3 \left( \frac{m_0}{m} \right)^2,$$

where $\Gamma_0$ is equivalent to $\Gamma(D^{*+})$, $m$ and $P$ are the measured candidate $D^{*+}$ mass and $\pi^+_\text{slow}$ or $D^0$ momentum in the $D^{*+}$ rest frame and $P_0$ and $m_0$ are the values computed using $Q_0$. The effect of the mass term is negligible at our energy. The partial width and the total width differ negligibly in their dependence on $Q$ for $Q > 1$ MeV. We use Eqn 3 suitably normalized to describe of $Q$ effects on width.
Table 1: Summary of our data sample, simulation biases, and fit results.

| Parameter                        | Nominal | Tracking | Kinematic |
|----------------------------------|---------|----------|-----------|
| Candidates                       | 11496   | 368      | 3284      |
| Background Fraction (%)          | 2.51 ± 0.27 | 4.1 ± 1.9 | 4.05 ± 0.49 |
| $\Gamma_\text{fit} - \Gamma_\text{generated (keV)}$ | 2.7 ± 2.1 | 1.7 ± 6.4 | 4.3 ± 3.1 |
| Fit $\Gamma_0$ (keV)             | 98.9 ± 4.0 | 106.0 ± 19.6 | 108.1 ± 5.9 |
| $D^{*+}$ Width (keV)             | 96.2 ± 4.0 | 104 ± 20  | 103.8 ± 5.9 |

Table 2: Results of the fits described in the text. The uncertainties are statistical.

| Parameter                        | Nominal | Tracking | Kinematic |
|----------------------------------|---------|----------|-----------|
| $\Gamma_0$ (keV)                | 98.9 ± 4.0 | 106.0 ± 19.6 | 108.1 ± 5.9 |
| $Q_0$ (keV)                      | 5853 ± 2  | 5854 ± 10 | 5850 ± 4   |
| $N_s$                            | 11207 ± 109 | 353 ± 20  | 3151 ± 57  |
| $f_{\text{mis}}$ (%)             | 5.3 ± 0.5 | NA       | NA         |
| $\sigma_{\text{mis}}$ (keV)      | 508 ± 39 | NA       | NA         |
| $N_b$                            | 289 ± 31  | 15 ± 7   | 133 ± 16   |

For each candidate the signal shape, $S$, is a convolution of the Breit-Wigner function with a resolution Gaussian with width, $\sigma_{Qi}$, determined by the tracking errors, as a model of our finite resolution. Figure 1 shows the distribution of $\sigma_Q$ for the data and the simulation. We allow a small fraction of the signal, $f_{\text{mis}}$, to be parameterized by a single Gaussian with effective resolution, $\sigma_{\text{mis}}$, different from measured, $\sigma_{Qi}$. This shape is included in the fit to model the tracking mishaps, mis-assigned hits and hard multiple scatters, which our simulation predicts to be at the 5% level in the nominal sample and negligible in both the tracking and kinematic selected samples. For the purpose of systematic study the $\sigma_Q$ has a scale factor, $k$, which is fixed to one in our nominal fits.

The fit also includes a background contribution with fixed shape, $B$, presented by polynomial function with three or more parameters, $b_{1,2,3}$. This shape is taken from fits to the background prediction of our simulation. The level of the background is allowed to float in our standard fit.

The fitter has been extensively tested both numerically and with input from our full simulation. We find that the fitter performs reliably giving normal distributions for the floating parameters and their uncertainties. It also reproduces the input $\Gamma(D^{*+})$ from 0 to 130 keV with offset consistent with zero, as shown in Table 1.

We note that if all the parameters are allowed to vary simultaneously there is strong correlation among the intrinsic width $\Gamma_0$, the fraction of mismeasured events $f_{\text{mis}}$, and the $\sigma_Q$ scale factor $k$, as one would expect. Thus our nominal fit holds $k$ fixed to one, but in our systematic studies we either fix one of the three or provide a constraint with a contribution to the likelihood if the parameter varies from its nominal value.

Figures 2, 3, and 4 respectively display the fit to the nominal, tracking, and kinematic selected data samples. The results of the fits are summarized in Table 2. Correlations among the floating parameters of the fit are negligible.

Figure 5 displays the likelihood as a function of the width of the $D^{*+}$ for the fits to the three data samples.

The agreement is excellent among the fits to three sample, and when the offsets are applied we obtain $D^{*+}$ widths listed in the last row in Table 1. The indicated uncertainties are only statistical.
We discuss the sources of systematic uncertainties on our measurements of the width of the $D^{*+}$ in the order of their size. The most important contribution is the variation of the result as a function of the kinematic parameters of the $D^{*+}$ decay. The next most important contribution comes from any mismodeling of $\sigma_Q$'s dependence on the kinematic parameters. We take into account correlations among the less well measured parameters of the fit, such as $k$, $f_{\text{mis}}$, and $\sigma_{\text{mis}}$, by fixing each parameter at $\pm 1$ standard deviation from their central fit values, repeating
Figure 5: Likelihood function versus measured $D^{*+}$ width for the nominal (left), tracking (center), and kinematic (right) selected data samples.

Table 3: Systematic uncertainties on the width of the $D^{*+}$ and $Q_0$

| Source                  | Uncertainties in keV | Sample   |               |               |               |               |
|-------------------------|----------------------|----------|---------------|---------------|---------------|---------------|
|                         | Nominal              | Tracking | Kinematic     |               |               |               |
| Running of $Q$          | 16                   | 15       | 16            | 15            | 16            | 15            |
| Mismodeling of $\sigma_Q$ | 11                   | < 1      | 9             | 4             | 7             | < 1           |
| Fit Correlations        | 8                    | 3        | 9             | 4             | 9             | 5             |
| Vertex Reconstruction   | 4                    | 2        | 4             | 2             | 4             | 2             |
| Background Shape        | 4                    | < 1      | 2             | < 1           | 2             | < 1           |
| Offset Correction       | 2                    | NA       | 6             | NA            | 3             | NA            |
| Data Digitization       | 1                    | 1        | 1             | 1             | 1             | 1             |
| Quadratic Sum           | 22                   | 15       | 22            | 16            | 20            | 16            |

The fit, and adding in quadrature the variation in the width of the $D^{*+}$ and $Q_0$ from their central values. We have studied in the simulation the sources of mismeasurement that give rise to the resolution on the width of the $D^{*+}$ by replacing the measured values with the generated values for various kinematic parameters of the decay products. We have then compared these uncertainties with analytic expressions for the uncertainties. The only source of resolution that we cannot account for in this way is a small distortion of the kinematics of the event caused by the algorithm used to reconstruct the $D^0$ origin point described above. We consider uncertainties from the background shape by allowing the coefficients of the background polynomial to float. Minor sources of uncertainty are from the width offsets derived from our simulation, and our data storage digitization resolution of 1 keV.

An extra and dominant source of uncertainty on $Q_0$ is the energy scale of our measurements. We are still evaluating the size of this contribution.

Table 3 summarizes the systematic uncertainties on the width of the $D^{*+}$ and $Q_0$.

In summary we have measured the width of the $D^{*+}$ by studying the distribution of the energy release in $D^{*+} \rightarrow D^0\pi^+$ followed by $D^0 \rightarrow K^-\pi^+$ decay. With our estimate of the systematic uncertainties for each of the three samples being essentially the same we chose to report the result for the sample with the smallest statistical uncertainty, the minimally selected sample, and obtain

$$\Gamma(D^{*+}) = 96 \pm 4 \pm 22\text{ keV}, \quad (3)$$
where the first uncertainty is statistical and the second is systematic.

This preliminary measurement is the first of the width of the $D^{*+}$, and corresponds to a strong coupling constants 3

$$g = 0.59 \pm 0.01 \pm 0.07 \quad \text{or} \quad g_{D^+D^0} = 17.9 \pm 0.3 \pm 1.9.$$  (4)

This is consistent with theoretical predictions based on HQET and relativistic quark models, but higher than predictions based on QCD sum rules and lattice calculations.

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References

1. Belyaev et al. *Phys. Rev.* D 51, 6177 (1995). contains a recent survey summarizing and referencing previous theoretical work. P. Singer, Acta Phys. Polon. B30 3849 (1999), J.L. Goity and W. Roberts JLAB-THY-00-45, [hep-ph/0012314](http://arxiv.org/abs/hep-ph/0012314) and M.Di Pierro and E.Eichten, [hep-ph/0104018](http://arxiv.org/abs/hep-ph/0104018) appear since that survey.
2. J. Bartelt et al. (CLEO Collaboration), *Phys. Rev. Lett.* 80, 3919 (1998).
3. M. Wise, *Phys. Rev.* D 45, R2188 (1992).
4. S. Barlag et al., *Phys. Lett.* B 278, 480 (1992).
5. Y. Kubota et al., (CLEO Collaboration), *Nucl. Instrum. Methods* A 320, 66 (1992); T. Hill, *Nucl. Instrum. Methods* A 418, 32 (1998).
6. R. Godang et al. (CLEO Collaboration), *Phys. Rev. Lett.* 84, 5038 (2000).
7. R. Brun et al., GEANT3 Users Guide, CERN DD/EE/84-1.
8. P. Billior, *Nucl. Instrum. Methods* A 225, 352 (1984).