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RECENT CHARM PHYSICS RESULTS AT CDF

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We present new measurements of branching ratios and CP violation of neutral and charged charmed mesons with the CDF II detector at Fermilab. Exploiting the high mass resolution of the CDF tracking system, the Cabibbo-suppressed decays $D^\circ \to K^+K^-$, $D^\circ \to \pi^+\pi^-$ and $D^\pm \to \pi^\mp\pi^\pm\pi^\pm$ are well separated from the much larger Cabibbo-favored decays, even without explicit particle identification, and their branching ratios have been measured with high precision. Accurate understanding of the tracking asymmetries allow us to search for direct CP violation in these decays by looking for an asymmetry in the decay rate of $C = 1$ and $C = -1$ mesons.

1 The Tevatron as a Charm Factory

Despite having a production cross section similar to bottom, charm is known[1] to dominate heavy flavor production at the Tevatron, thanks mostly to favorable branching fractions in reconstructable modes. Event selection strategies have –in the past– limited the c contribution to a secondary role in terms of physics capabilities of our detectors. Now, with the advent of new lifetime-based trigger strategies[2], CDF has access to considerably larger samples of charm decays.

An overview of the current status and performance of the Tevatron and of the CDF II experiment can be found in this reference[3].

1.1 Charm Production Mechanisms at the Tevatron

D mesons and their known radial and orbital excitations are all expected to be produced – and in fact are observed – at the Tevatron. Both prompt and secondary production (from b flavored particles) mechanisms are significant and yield competitive results with both b and c factories. This paper will focus mostly on *prompt* charm production.

1.2 Production Rates

Lifetime based event selections like the one implemented in CDF[2] are in fact more effective in collecting promptly produced charmed particles than b flavored mesons, despite the fact that B mesons are typically longer lived than D mesons. This is a consequence of the relatively large charm branching fractions in low multiplicity charged modes. Figure 1 shows, as an example, the amount of $D^+ \to K\pi\pi$ mesons collected in the first 193 pb^{-1} of data recorded at CDF II. While there are millions of such candidates, the fully reconstructed B meson samples at similar integrated luminosities are of the order of thousands of events[4].

The impressive amount of D mesons collected provides not only a very useful diagnostic tool for our infrastructure (detector components and reconstruction code), but also a new physics opportunity at $p\bar{p}$ colliders: the Tevatron has every right to be considered a charm factory.

1.3 Non Prompt Charm Physics

Historically charm physics has been explored mostly in prompt charm production. In more recent times, B factories have had the opportunity of investigating both prompt and non prompt charm production, achieving important results also in the $b \to c$ sector: the determination of V_{cb} and the measurement of moments in semileptonic B decays are two of the most important examples. These topics are being extensively dis-

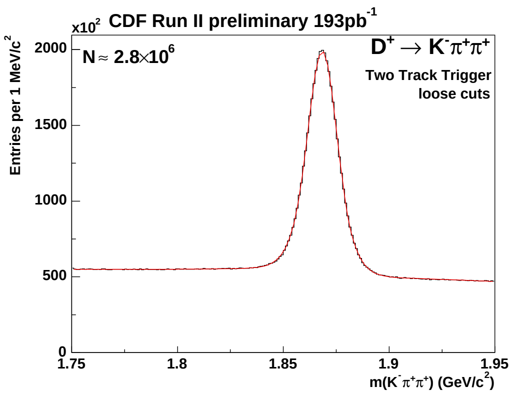

Figure 1. Invariant mass distribution for $D^+ \to K\pi\pi$ candidates collected in about 190 pb^{-1} of CDF II data.

Meson	P_t	f [%]	X [μb]
D°	5.5	86.6 ± 0.4	$13.3 \pm 0.2 \pm 1.5$
D^{*+}	6.0	88.1 ± 1.1	$5.2 \pm 0.1 \pm 0.8$
D^+	6.0	89.1 ± 0.4	$4.3 \pm 0.1 \pm 0.7$
D_s^+	8.0	77.3 ± 3.8	$0.75 \pm 0.05 \pm 0.22$

Table 1. D meson cross section (X) and relative prompt fraction (f) for each species. Each cross section is measured for $|y| \leq 1$ and with the P_t threshold in GeV/c specified in the table.

cussed elsewhere in these proceedings, both for b/c specific experiments[5,6,7] and at collider experiments[3,5,8]. CDF is contributing also in this sector, but the discussion in this paper will be limited to the prompt samples, since the current activity on non prompt charm samples has been covered here[5].

1.4 Prompt Charm

CDF is obtaining several interesting results on charm physics using prompt charm samples. In the remainder of this paper we will walk through a selection of them, first providing results for the D meson production cross sections, then focusing on the possibility of investigating properties of D^{**} states at CDF. Subsequently, we will then discuss the experiment's plans for contributing to CP violation measurements in the c sector, outlining current results (Cabibbo suppressed) and near future prospects (doubly Cabibbo suppressed D° decays and $D^+ \to K\pi\pi/\pi\pi\pi$).

2 Charm Cross Section

Using only 5.8 ± 0.3 pb^{-1} of data CDF was able to obtain precise measurements of the integrated and differential $d\sigma/dp_T$ cross sections for D, D^*, D^+ and D_s mesons pro-

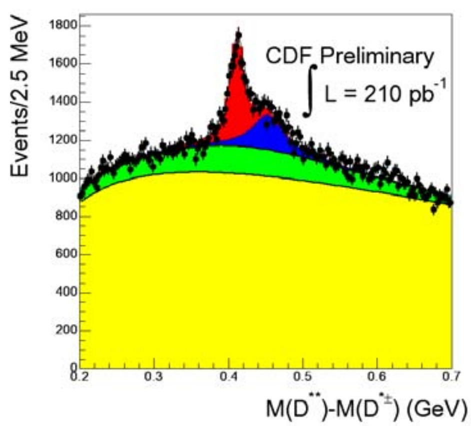

Figure 2. Invariant mass distribution for $D_{1,2} \to D^{*+}\pi^-$, $D^{*+} \to D^\circ\pi^+$, $D^\circ \to K^-\pi^+$ candidates collected in about 210 pb^{-1} of CDF data. The two narrow resonant components correspond to the contribution of the D_1 and D_2 resonances.

duced with $|y| \leq 1$ and a P_t threshold ranging between 5.5 and 8 GeV/c. Together with the cross section, also the fraction of mesons coming from prompt sources – as opposed to secondary-produced charm – is also measured. Both quantities are summarized for each species in table 1 The details of this measurement are reported in this reference[1].

3 D^{**} Production at CDF

Figure 2 shows the invariant mass distribution for $D_{1,2} \to D^{*+}\pi^-, D^{*+} \to D^\circ\pi^+$, $D^\circ \to K^-\pi^+$ candidates, less the D^* candidate mass. Both the $D^{*+}\pi^-$ and the

$D^+\pi^-$ modes have been reconstructed, collecting so far a sample of the order of 10000 $D_{1,2}$ decays: the largest available from single experiment[9].

Samples of this size are an invitation to perform precision measurements. As a benchmark, CDF performed the measurement of the masses and widths of the $D_{1,2}$ states, and of the mass difference relative to the D^{*+} meson, which suffers from smaller systematics than the absolute mass measurements[9]:

$$M(D_1) - M(D^{*+}) = 411.7 \pm 0.7 \pm 0.4\, MeV$$
$$M(D_1) = 2421.7 \pm 0.7 \pm 0.6\, MeV$$
$$\Gamma(D_1) = 20.0 \pm 1.7 \pm 1.3\, MeV$$
$$M(D_2) - M(D^{+}) = 594.0 \pm 0.6 \pm 0.5\, MeV$$
$$M(D_2) = 2463.3 \pm 0.6 \pm 0.8\, MeV$$
$$\Gamma(D_2) = 49.2 \pm 2.3 \pm 1.3\, MeV$$

Thanks to the large statistics of the sample and the ability to control systematic errors accordingly, these results are extremely competitive with the current PDG averages and single experimental results[10].

4 CP violation

CDF is approaching the issue of constraining the charmed mesons CP violation parameters x and y[11]. There are three methods currently being followed: the first one looks at Cabibbo suppressed D° decays to $K^\pm K^\mp$ and $\pi^\pm\pi^\mp$, where the CP asymmetry shows up as a difference in lifetime between these modes and the canonical $D^\circ \to K^-\pi^+$. The second method aims at the measurement of the relative ratio $\Gamma(D^\circ \to K^+\pi^-)/\Gamma(D^\circ \to K^-\pi^+)$ as a function of time. A third method explores the measurement of the CP asymmetry in $D^\pm \to \pi^\mp\pi^\pm\pi^\pm$[12].

4.1 Cabibbo Suppressed D° Decays

Using about 123 pb^{-1} of data collected by CDF during the 2002/2003 data-taking, we measure the relative branching ratios $\Gamma(D^\circ \to K^+K^-)/\Gamma(D^\circ \to K^-\pi^+)$ and $\Gamma(D^\circ \to \pi^+\pi^-)/\Gamma(D^\circ \to K^-\pi^+)$ and perform the first measurement of the direct CP-violating decay rate asymmetries in CDF.

$D^\circ \to K^-\pi^+$, $D^\circ \to K^+K^-$ and $D^\circ \to \pi^+\pi^-$ candidates are collected through the CDF "hadronic trigger", which requires the presence of vertexes displaced with respect to the interaction point. Reconstruction consists in forming vertexes of opposite charged tracks and matching the offline-reconstructed vertex to the one selected at trigger level.

The reconstructed D° candidates are then combined with a soft pion track to reconstruct the final $D^{*\pm}\pi^\mp$ candidates. The charge of the soft pion is required to match the charge of the pion from the D° decay. About 180000 $D^\circ \to K^-\pi^+$, 16000 $D^\circ \to K^+K^-$ and 7000 $D^\circ \to \pi^+\pi^-$ candidates (tagged with D^*), pass our selection cuts based on few simple quantities: D° impact parameter less than $100\,\mu m$, projected decay length of the D° meson $L_{xy} > 350\,\mu m$, $\Delta M = M(D^*) - M(D^\circ)$ inside a 3σ window ($\sigma \approx 0.6\,MeV/c^2$) around the expected value, and the product of the impact parameters of the two D° daughters less than or equal to zero.

We then determine the relative branching ratios as $\frac{\Gamma(D^\circ \to KK(\pi\pi))}{\Gamma(D^\circ \to K\pi)} = \frac{N_{KK(\pi\pi)}}{N_{K\pi}} \cdot \frac{\epsilon_{K\pi}}{\epsilon_{KK(\pi\pi)}}$ where N_{hh} is the observed number of D° decaying in the appropriate mode in our data and ϵ_{hh} is the overall acceptance for each of the decay modes. The latter term includes both trigger and offline reconstruction efficiencies, and is estimated using a complete simulation of the CDFII detector, including realistic emulation of the trigger, the effects of the nuclear interactions and decay in flight of kaons and pions as well as time dependent detector inefficiencies.

We use the same procedure to search for the direct CP asymmetries $A_{CP} = \frac{\Gamma(D^\circ \to f) - \Gamma(\bar{D}^\circ \to f)}{\Gamma(D^\circ \to f) + \Gamma(\bar{D}^\circ \to f)}$ where f can be either K^+K^- or $\pi^+\pi^-$. The charge of the slow pion from the $D^{*\pm} \to D^\circ\pi^\pm$ decay serves as an unbiased tag of the D° flavor.

We correct for the intrinsic charge asymmetry of the CDFII detector studying this effect on samples of unbiased tracks as a function of the track transverse momentum, and testing any possible residual effect after the correction on independent samples of meson decays where CP-asymmetry is not expected.

Our largest sources of systematic error for the relative branching ratios come from the background model, the lifetime difference between the D° mass eigenstates, and the MC statistic. Other sources of systematic uncertainty are in the estimate of the relative acceptance and in possible contamination from non prompt D° production. The dominant systematic for the direct CP asymmetry measurements is the correction for the charge asymmetry for low momentum tracks in the CDFII tracking system. Significant sources of systematic errors arise from the reliance of the relative efficiency estimate on the MC Pt input spectrum, the description of the Tevatron beam shape in Z, and the uncertainties on the nuclear interactions for hadronic particles in GEANT. The resulting measurements are competitive with the available results[10], and they are reported below with, respectively, the statistical and systematic errors:

$$\frac{\Gamma(D^\circ \to K^+K^-)}{\Gamma(D^\circ \to K\pi)} = 9.92 \pm 0.11 \pm 0.12\,\%$$

$$\frac{\Gamma(D^\circ \to \pi^+\pi^-)}{\Gamma(D^\circ \to K\pi)} = 3.594 \pm 0.054 \pm 0.040\,\%$$

$$\frac{\Gamma(D^\circ \to K^+K^-)}{\Gamma(D^\circ \to \pi\pi)} = 2.760 \pm 0.040 \pm 0.034\,\%$$

$$A(D^\circ \to K^+K^-) = 2.0 \pm 1.2 \pm 0.6\,\%$$

$$A(D^\circ \to \pi^+\pi^-) = 1.0 \pm 1.3 \pm 0.6\,\%$$

4.2 Doubly Cabibbo Suppressed Decays

Current experimental results for the measurement of $\Gamma(D^\circ \to K^+\pi^-)/\Gamma(D^\circ \to K^-\pi^+)$ are based on O(500) events[13]. Given the amount of $D^{*+} \to D^\circ\pi$ collected with $D^\circ \to K\pi$ and the relative production rate $\Gamma(D^\circ \to K^+\pi^-)/\Gamma(D^\circ \to K^-\pi^+)$ from PDG[10], we expect to have already collected O(1000) fully reconstructable $D^\circ \to K^+\pi^-$ events. Work is in progress in order to understand how competitive we are going to be with this sample.

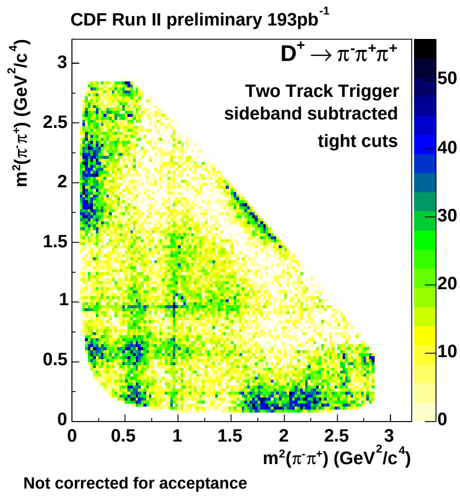

Figure 3. Dalitz plot sideband subtracted distribution for the decay $D^\pm \to \pi^\mp\pi^\pm\pi^\pm$.

4.3 CP violation in D^+ Decays

Three million D^+ candidates are an excellent tool for studying detailed properties of D^+ decays. They give, for instance, access to detailed features like Dalitz plot contours to experiments in an environment traditionally considered not clean enough for this kind of studies. A central role in CP violation in D^+ decays is played by $D^\pm \to \pi^\mp\pi^\pm\pi^\pm$, for which CDF has collected roughly 55000 candidates in 193 pb^{-1}: figure 3 shows the structure of the Dalitz plot as observed for this sample, where it is easy to recognize the presence of expected intermediate resonances such as the $\rho(770)$ and $f^\circ(980)$. Our plan is to first exploit these events to improve the knowledge on $\Gamma(D^\pm \to \pi^\mp\pi^\pm\pi^\pm)$ and then explore our capabilities in measuring the CP asymmetry in this very same decay mode.

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