Search for $\Lambda_c^+ \to pK^+\pi^-$ and $D_s^+ \to K^+K^+\pi^-$ Using Genetic Programming Event Selection

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Abstract. We apply a genetic programming technique to search for the doubly Cabibbo suppressed decays $\Lambda_c^+ \to pK^+\pi^-$ and $D_s^+ \to K^+K^+\pi^-$. We normalize these decays to their Cabibbo favored partners and find $\mathrm{BR}(\Lambda_c^+ \to pK^+\pi^-)/\mathrm{BR}(\Lambda_c^+ \to pK^-\pi^+) < 0.46\%$ and $\mathrm{BR}(D_s^+ \to K^+K^+\pi^-)/\mathrm{BR}(D_s^+ \to K^-K^+\pi^+) < 0.78\%$ at the 90% confidence level (CL). This is the first successful use of genetic programming in a high energy physics data analysis.

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Cabibbo suppressed (CS) and doubly Cabibbo suppressed (DCS) decays are important in helping us understand the dynamics of hadronic decay processes. DCS decays are unique to the charmed hadrons; charm is the only heavy up-type quark that hadronizes. Naïve expectations place DCS branching ratios around $\tan^4\theta_c$, or about 0.25%, relative to their Cabibbo favored (CF) counterparts.

We have applied a genetic programming (GP) [1] technique to search for the DCS decays $D_s^+ \to K^+K^+\pi^-$ and $\Lambda_c^+ \to pK^+\pi^-$ (charge-conjugate states are implied), neither of which have been observed. GP is a machine learning technique which evolves populations of programs (event filters in our case) over a series of generations. The genetic programming learning mechanism is modeled on biological and evolutionary principals. We have found that this unbiased method can be more effective in separating signal events from backgrounds than standard, cut based, methods. A full demonstration of this technique on the observed DCS decay $D^+ \to K^+\pi^+\pi^-$ is given in Ref. [2].

These results use data from the charm photoproduction experiment FOCUS, an upgraded version of FNAL-E687 [3] which collected data using the Wideband photon beamline during the 1996–1997 Fermilab fixed-target run. FOCUS utilizes a forward multiparticle spectrometer to study charmed particles produced by the interaction of high energy photons with a segmented BeO target.

We use loose analysis cuts on both DCS and CF decay modes to select initial samples of events for optimization by GP. The initial samples of Λ_c^+ and D_s^+ candidates in CF and DCS decay modes are shown in Figs. 1 & 2 respectively.

A GP framework (GPF) evolves and tests event filters. For each filter, we define a fitness, $f \propto B_{\mathrm{DCS}}/S_{\mathrm{CF}}^2 \times (1 + 0.005 \times N_{\mathrm{nodes}})$, where B_{DCS} is the number of background events found in a fit of the DCS mass distribution which excludes the signal region, and S_{CF} is the fitted CF yield. $S_{\mathrm{CF}}/\sqrt{B_{\mathrm{DCS}}}$ is proportional to the projected DCS significance assuming no real DCS events and equal CF and DCS selection efficiencies; squaring this quantity further emphasizes "better" filters and inverting it allows small fitnesses to describe good event filters. N_{nodes} is the total number of variables, constants, functions,

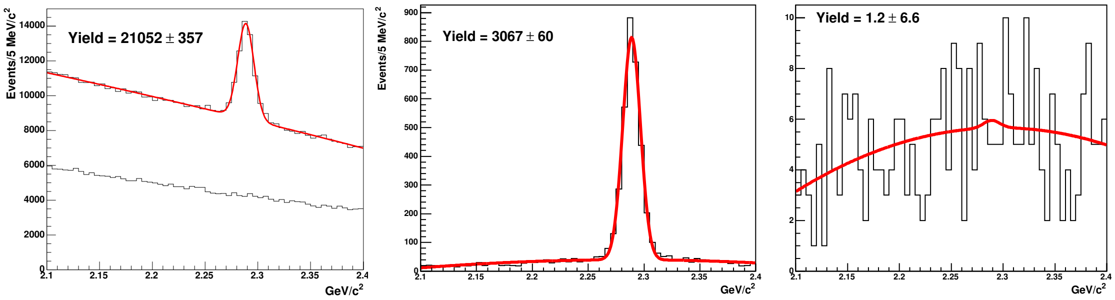

FIGURE 1. Λ_c^+ samples before and after selection. On the left are the initial event samples (CF on top, DCS) on bottom. In the center are the selected CF events. On the right are the selected $\Lambda_c^+ \to pK^+\pi^-$ candidates.

and operators used in the filter and is included to encourage smaller filters.

The selected events along with a large number of variables (37 for Λ_c^+, 34 for D_s^+), operators and functions (21), and constants are used as inputs to the GPF which randomly generates a large number of filters and calculates the fitness of each. The GPF preferentially selects filters for which this fitness is small to participate in breeding subsequent generations of filters. In this way subsequent generations develop filters with better average fitnesses. At the end of the process we use the filter with the single best fitness to select events for further analysis. The variables and resulting filter used in the CF and DCS decays are identical.

All variables commonly used in FOCUS analyses and some additional variables are allowed to be used in the event filter. These can be roughly broken into categories of vertexing, track quality, particle identification, production and decay kinematics, and away-side charm tagging. A description of the variables used, examples of the event filters constructed, and how the population of filters evolves over many generations can be found in Ref. [2].

When searching for $\Lambda_c^+ \to pK^+\pi^-$ and $D_s^+ \to K^+K^+\pi^-$ decays (with the signal regions masked), the GPF is allowed to run for 80 generations. The best $\Lambda_c^+ \to pK^+\pi^-$ filter found has 45 nodes and uses 12 unique physics variables. The events selected are shown in Fig. 1. One can see that about 15% of the signal is retained while the backgrounds are reduced by a factor of $\sim$1000. The distributions in both the CF and DCS cases are fit with a polynomial and a Gaussian. In the DCS case, the Gaussian mean and σ are fixed to the CF values and we find 1.2 ± 6.6 DCS events.

The best $D_s^+ \to K^+K^+\pi^-$ filter found has 85 nodes and uses 15 unique physics variables. The events selected are shown in Fig. 2. The fits shown are performed similarly to the Λ_c^+ case except that an additional Gaussian is added to the CF distribution for the CS decay $D^+ \to K^-K^+\pi^+$. We find 27.5 ± 9.2 events in the DCS distribution.

In both cases our central values are calculated assuming non-resonant decays for the DCS case and the best known resonance models for the CF decays (the PDG [4] model for Λ_c^+ and a FOCUS model for D_s^+).

Using the errors and yields above, efficiencies from MC simulations, and estimates of the systematic errors, we follow the method proposed by Convery [5] to obtain limits on

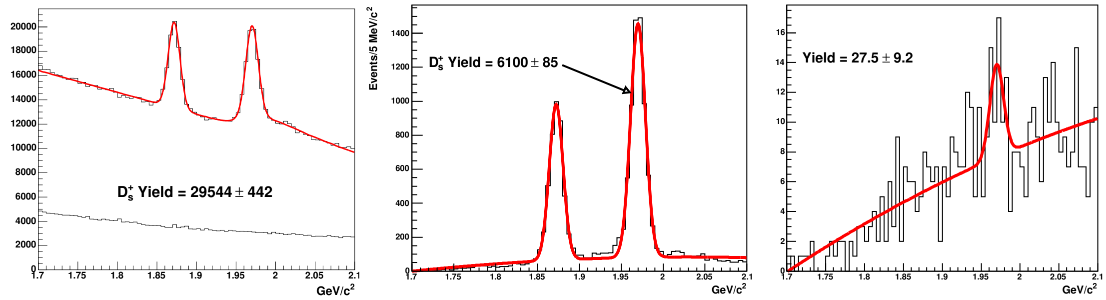

FIGURE 2. D_s^+ samples (right-hand peak) before and after selection. On the left are the initital event samples (CF on top, DCS) on bottom. In the center are the selected CF events. On the right are the selected $D_s^+ \to K^+K^+\pi^-$ candidates.

the relative BRs. We find

$$\frac{\mathrm{BR}(\Lambda_c^+ \to pK^+\pi^-)}{\mathrm{BR}(\Lambda_c^+ \to pK^-\pi^+)} < 0.46\% \tag{1}$$

and

$$\frac{\mathrm{BR}(D_s^+ \to K^+K^+\pi^-)}{\mathrm{BR}(D_s^+ \to K^-K^+\pi^+)} < 0.78\% \tag{2}$$

where the limits are at the 90% CL. Both limits are larger than the expected $\mathscr{O}(\tan^4\theta_c)$ level, but are the first reported limits on these decays. Furthermore, this is the first successful application of the GP technique to an HEP data analysis. A full description of this analysis, including a discussion of systematic errors can be found in Ref. [6].

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