Inclusive measurement of $\Lambda_c^+ \to e^+ X$

Matt Cervantes

Departments of Physics and Mathematics

University of Kansas, Lawrence, KA 66045

Introduction

Making the inclusive measurement of $\Lambda_c^+ \to e^+$X allows for a direct determination of the semileptonic branching fraction, while also providing an indirect determination of the $\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)$. Russell P. Stutz explicitly determined $\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+) = (5.0 \pm 0.5 \pm 1.5)\%$ by measuring the p$K^-\pi^+$ yield in the same hemisphere as tagged $\overline{p}$ events.

However, there is another method which provides an indirect determination of $\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)$. This method requires the assumption that the semileptonic decay widths for the $\overline{D^0}$ meson and Λ_c^+ baryon are equal. The Particle Data Group makes use of this assumption to determine $\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+) = (5.0 \pm 1.3)\%$. A highly accurate test of this assumption is the subject of this paper.

Theory

The semileptonic decay channel $\overline{D^0} \to e^+$X has been measured and documented to a high level of accuracy. However, the process by which this meson decays is through the external emission of a W^+ boson, during which the u quark is not believed to influence the final decay and is said to be a "spectator quark". This model of the spectator quark for the $\overline{D^0}$ has conveniently been carried over to Λ_c^+ semileptonic decays. Here the u and d quarks do not participate in the model of such events. This follows from the assumption that the light u and d quarks do not participate in such decays due to high magnetic and chromomagnetic coupling. Therefore it has been assumed that the spectator model and thus the equivalence of the semileptonic decay widths of the $\overline{D^0}$ and the Λ_c^+ are valid. Although Λ_c^+ is allowed to undergo internal W emissions known as internal spectator decays, the non-external spectator modes do not change the external spectators partial width. This does however change the overall lifetime of the Λ_c^+ since $\Gamma_{total} = \Gamma_{externalWmodes} + \Gamma_{internalWmodes}$. The result is that the total semileptonic width remains the same and the semileptonic branching fraction of Λ_c^+ decreases.

The assumption that the semileptonic widths of $\overline{D^0}$ and Λ_c^+ are equal may be incorrect if the simple quark emission picture is wrong. As of now this model is already seen as an oversimplification since the hadrons containing quarks are the observable, while the quarks themselves are not observed. This leads to an expectation that a more accurate description of the model will include the effect of a charm quark decaying into the strange daughter quark. The production of a strange quark during charm decay is therefore indirectly observed in the form of visible hadrons, leading to an oversimplified model. This effect alone will change the overall semileptonic widths of the $\overline{D^0}$ and the Λ_c^+.

Analysis Method

This analysis depends on $e^+e^- \rightarrow c\bar{c}$ events. The suppression of $b\bar{b}$ events is achieved by making momenta cuts on the particles such that contamination from lower momenta particles produced during $b\bar{b}$ events is minimal. Event selection is further restricted by requiring a $\overline{D^0}$ in the opposite hemisphere of both an identified $\overline{p}$ and a tagged lepton daughter particle of the Λ_c^+. Although the Λ_c^+ mother is not observed directly, it is likely to be present compensating for both charm and baryon number during the fragmentation process. This tagging method used was used by Russel P. Stutz during $\Lambda_c^+ \rightarrow pK^-\pi^+$ measurements and is believed to be highly accurate. The equation below outlines the physical process of our interest.

$$
\begin{array}{ccccc}
 & & c\quad\overline{c} & & \\
 & \overline{p} \hookleftarrow & & \hookrightarrow D^{*-} & \\
 & \Lambda_c^+ \hookleftarrow & & & \hookrightarrow \overline{D^0}\pi^-_{soft} \\
e^+X \hookleftarrow & & & &
\end{array}
$$

Triple Correlations

The technique used during the inclusive measurement of $\Lambda_c^+ \rightarrow e^+$X is dependent upon the isolation of $e^+e^- \rightarrow c\bar{c}$ events. The events sample in question is further constrained by triple correlations. The equation above shows the final state of the fragmentation process to be analyzed. It is at this stage that certain parameters in order to test for Λ_c^+ particles are to be defined. The process in question is that of a semileptonic Λ_c^+ decay. The semileptonic daughters of such events are tagged by selecting leptons among all the leptons (and fake leptons) in our candidate events by requiring the leptons associated with Λ_c^+ decays to be associated with the $c\bar{c}$ "jet thrust axis". Our criteria for event reconstruction also requires the identification of $\overline{D^0}$ and $\overline{p}$. The $\overline{D^0}$ is reconstructed from a channel consisting of the k^+ π^-.

The identification and tagging of events containing the appropriate lepton, $\overline{D^0}$, and $\overline{p}$ correlations yields a raw signal of events to work with. Further requiring that these candidate events are those which are indicated in the above equation requires that a hemisphere cut be made such that all events passing defined lepton, $\overline{D^0}$, and $\overline{p}$ cuts have the proper hemisphere correlations. That is, a tagged $\overline{D^0}$ must be located in the opposite hemisphere of both tagged lepton and $\overline{p}$ events.

Events in which D^- has been reconstructed from $k^+\pi^-\pi^-$ are also utilized. The same hemisphere correlations as the $\overline{D^0}$ triple correlations are required. Another tagging method known as soft pion tagging is also employed. The use of π^-_{soft} will increase the efficiency of tagging events compared to the less efficient reconstruction of $\overline{D^0}$ or D^- from their respective daughter particles. The soft pion is characterized as having a low opening angle (θ) with respect to the $c\bar{c}$ thrust axis event. This low opening angle is a consequence of the low residual phase space available (i.e. Q value) and momentum conservation of the D^{*-} decay. Therefore soft pion tags in our triple correlation will be projected onto the $sin^2\theta$ axis and the number of soft pion events are contained under the signal region as $sin^2\theta \rightarrow 0$.

Although our event sample of electrons coming from Λ_c^+ decay have strong cuts, there are other charmed baryons which could allow for a cleaner event sample. Such events include $\Sigma_c^0 \rightarrow \Lambda_c^+ + \pi_{soft}^-$ (100%) . These decays and contributions from excited states of Σ_c as well as excited states of the Λ_c^+(e.g. Λ_c^+(2593) and Λ_c^+(2630)) will systematically be explored as triple correlations.

Triple Correlation using neutrals

During external semileptonic decays of the Λ_c^+ a Λ^0 is produced. Subsequently the decay of the Λ^0, governed by the weak force, results in the production of protons or neutrons in association with the appropriate charge conserving pion. However, non-semileptonic decays of the Λ_c^+ will produce other protons and neutrons not necessarily associated with Λ^0 decays. Subtle differences in the behavior of neutrons through a calorimeter vs. antinuetrons (composed of antiquarks) through a calorimeter is under consideration as another means to account for total Λ_c^+ production. This technique will require the suppression of photons from unwanted sources(e.g. $\pi^0 \rightarrow \gamma\gamma$) and rely on the detection of neutral showers from (anti)neutron interactions within the calorimeter.

Fakes and Efficiency

Suppression of particle fakes is a major part of providing the purest signal possible. As mentioned, the isolation of $e{+}e^- \rightarrow \mathrm{c\bar{c}}$ occurs through high momentum cuts on the particles involved in the triple correlations. This will significantly reduce background associated with $\mathrm{c\bar{c}}$ events produced during the production and decay of $\mathrm{b\bar{b}}$. Great effort is underway to identify any events that are not a part of our triple correlated signals and systematic removal is in progress . These efforts include the requirement of high likelihood cuts on particles in our event sample. However, contamination from alternative decay modes of our triple tagged events is possible and will have to be identified with Monte Carlo simulation. Monte Carlo is now in progress and the rate at which kaons, pions, muons, and electrons all fake protons are being explored. Fake rates for kaons, pions, muons, and protons faking electrons is under investigation as well.

Use of the Monte Carlo will also determine the efficiency with which our particles are actually identified. The efficiency value derived from the Monte Carlo frame is then assumed to be equal to the efficiency of our detector and efficiency corrections will then be applied to signal events from the data.

Cross-checks

Techniques using the various triple correlations(cross-checks) suggested will result in varied signal events in each of the respective continuum samples. However, the physical process of $\Lambda_c^+ \rightarrow e^+\mathrm{X}$ is independent of which triple correlation is used (within statistical limits and efficiency corrections), therefore the same semileptonic branching fraction should be found. Shown below is the branching fraction equation as is relates to the experimentally determined values.

$$\mathcal{B}(\Lambda_c \to e^+\nu X) = \frac{\frac{N(e^+\nu X)^{tagged}_{observed} - e^+_{fakes}}{\epsilon_{e^+}}}{N^{tags}_{total} - N^{fakes}_{total}}$$

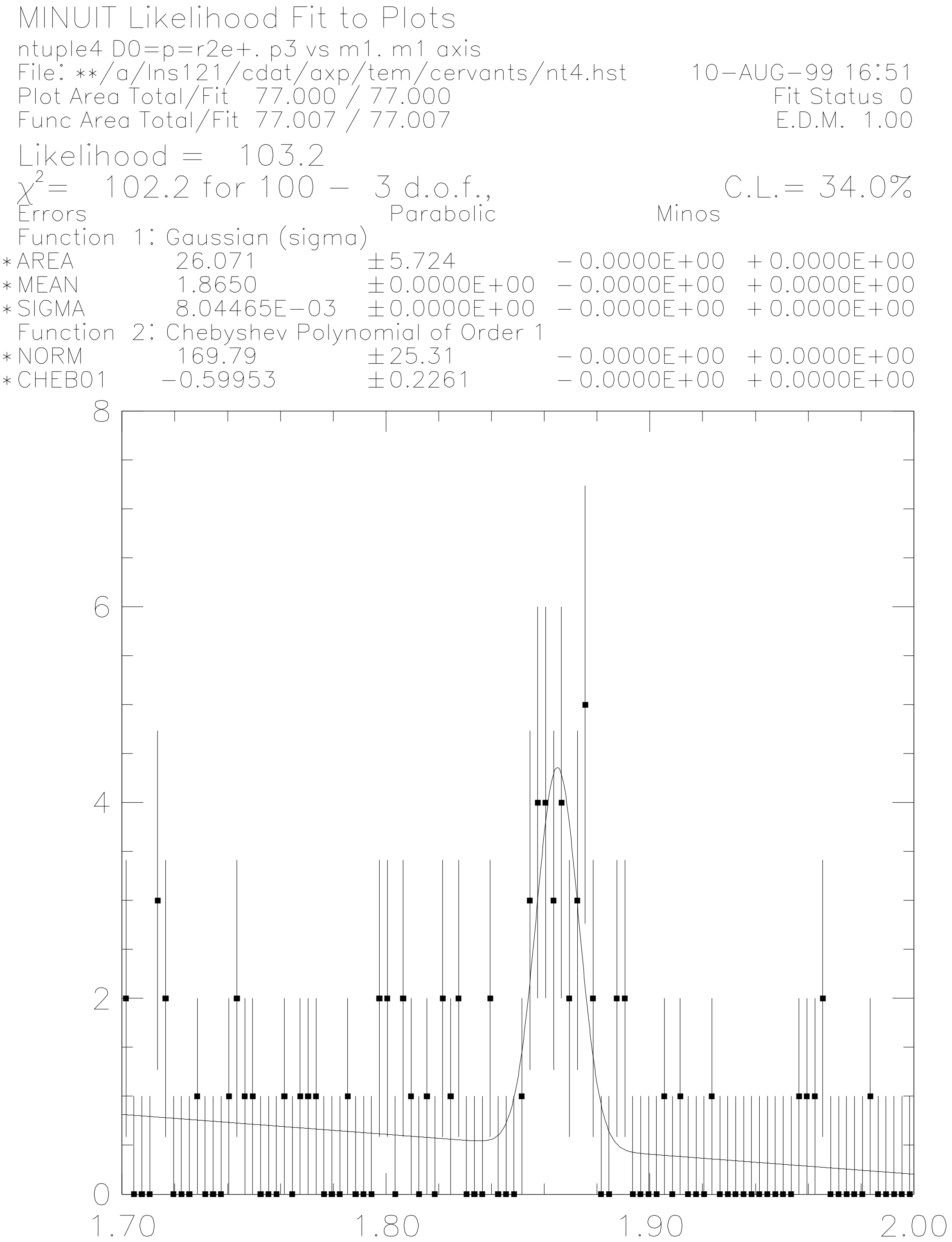
- $N(e^+\nu X)^{tagged}_{observed} \equiv$ Number of events associated with $\overline{p}$ tags and uncorrected for efficiency
- $e^+_{fakes} \equiv$ Number of fake e^+ to be subtracted from signal
- $N^{tags}_{total} \equiv$ Number of $\overline{p}$ opposite a $\overline{D^0}$, D^-, or π^-_{soft}
- $N^{fakes}_{total} \equiv$ Number of total fake events
- $\epsilon_{e^+} \equiv$ The efficiency of detecting e^+ determined by Monte Carlo frame

Results

The analysis at this stage is still in progress and as a result no value will be quoted here for $\mathcal{B}(\Lambda_c \to e^+\nu X)$. As mentioned, multiple cross-checks and systematic removal of background events are being performed to insure the accuracy of this measurement. The following histogram represents the presence of our $\Lambda_c^+ \to e^+$X signal uncorrected for “fakes” and efficiency. The yield is 26 signal(uncorrected) events. The event sample contains 80 million CLEO II and II.V events.

Acknowledgments

I am pleased to thank Prof. David Besson of the University of Kansas and Prof. Ed Thorndike of the University of Rochester, who proposed this Research Experience for Undergraduates project and guided my effort. This work was supported by National Science Foundation REU grants PHY-9605065 and PHY-9731882 and research grant PHY-9809799.



```
MINUIT Likelihood Fit to Plots
ntuple4 D0=p=r2e+. p3 vs m1. m1 axis
File: **/a/lns121/cdat/axp/tem/cervants/nt4.hst       10-AUG-99 16:51
Plot Area Total/Fit   77.000 / 77.000                       Fit Status  0
Func Area Total/Fit  77.007 / 77.007                        E.D.M.  1.00
Likelihood =   103.2
χ²=   102.2 for 100 -  3 d.o.f.,                       C.L.= 34.0%
Errors                          Parabolic              Minos
 Function  1: Gaussian (sigma)
*AREA          26.071         ±5.724         - 0.0000E+00  + 0.0000E+00
*MEAN          1.8650         ±0.0000E+00    - 0.0000E+00  + 0.0000E+00
*SIGMA         8.04465E-03    ±0.0000E+00    - 0.0000E+00  + 0.0000E+00
 Function  2: Chebyshev Polynomial of Order 1
*NORM          169.79         ±25.31         - 0.0000E+00  + 0.0000E+00
*CHEB01       -0.59953        ±0.2261        - 0.0000E+00  + 0.0000E+00
```

FIGURE 1. This is a plot of the triple correlated signal of $\Lambda_c^+ \rightarrow e^+ X$. This figure represents $\overline{D^0}, \overline{p}, r2e^+$ correlations projected onto the $\overline{D^0}$ invariant mass axis.