Missing Mass Recoiling Against the Charged D^*
Monte Carlo Based Investigation of a BaBar Recoil Peak at 2620 MeV

Hillary Cain
Office of Science, SULI Program
Dartmouth College
Stanford Linear Accelerator Center
Menlo Park, California 94025

August 19, 2003

Prepared in partial fulfillment of the requirements of the Office of Science, DOE Student Undergraduate Laboratory Internship (SULI) Program under the direction of Arthur Snyder and Steve Wagner in Group C (the Research Division) at Stanford Linear Accelerator Center.

Participant:

Signature

Research Advisor:

Signature

Table of Contents

Abstract	1
Introduction	2
Materials and Methods	4
Results	5
Discussion and Conclusions	6
Acknowledgements	7
References	7
Figures	8

Abstract

Missing Mass Recoiling Against the Charged D^* : Monte Carlo Based Investigation of a BaBar Recoil Peak at 2620 MeV. HILLARY CAIN (Dartmouth College, Hanover, NH, 03755)
ARTHUR SNYDER, STEVE WAGNER (Stanford Linear Accelerator Center, Menlo Park, CA 94025).

This paper chronicles the investigation of a peak in the BaBar mass data set of mass recoiling against charged D^{*} 's. Our hypothesis is that the peak at 2620 MeV is a reflection of the D_s^{*+} and π system. Specifically, we explored the idea that the peak might be a reflection from the decay $B \rightarrow D^{*-} D_s^{*+}$ with the $D^{*-} \rightarrow D^{*-} \pi$. Theoretically, when the D^{*-} decays, the trajectory of the resulting π will form an angle with the D_s^{*+} , and different angles impart difference masses to the system over a range of a GeV or so. If quantum mechanics dictates that their paths will form a particular angle more often than others, a peak would appear in the histogram of their collective mass. Using the Monte Carlo model of particle collision events, Anders Ryd's EVTGEN program, C++ code derived from GeneratorsQA, and PAW, we tested the hypothesis that the peak might be a reflection of the system, but found that this possible explanation could not account for the peak. No 2620 MeV peak appears in the histogram of the system mass. We therefore discount the hypothesis and conclude that some other reflection, statistical fluctuation, or particle is causing the peak.

INTRODUCTION

The BaBar (B and B bar factory) detector at SLAC (Stanford Linear Accelerator) was built to chronicle the decays of rare particles, but frequently the decays are so rare and so swift that it's not clear whether a signal in the data is a statistical fluctuation, a "reflection" of an already known particle, or an exciting new particle. Reconstructing particle collisions and decays is necessarily a vague process because of the uncertainty principle and because of limitations on the sensitivity of the detector equipment. So when one of my summer mentor, Arthur Snyder, noticed a peak in the plot of the mass recoiling against D^{*-} 's in B decays, he started me on a project utilizing the Monte Carlo (MC), a data set modeling the BaBar data based on the current understanding of particle physics, to test whether the peak at 2620 MeV could be just a reflection. We followed up John Bartelt's suggestion that the peak at 2620 MeV was a reflection of the decay from $B \rightarrow D^{*-} D_s^{*+}$ with the $D^{*-} \rightarrow D^{*-} \pi$ [1].

Reflections occur when a system of particles have a distribution of masses depending on the angles between their trajectories. The plot of the D_s^{*} and π system's mass should sharply drop off at mass values determined by the maximum and minimum angles between the two meson's trajectories. When the D_s^{*} and the π are expelled parallel to each other at an angle of zero, their system has the lightest mass, while the system mass is heaviest if they travel in opposite directions so that their angle is 90 or -90 degrees apart. The mass function's dependence on angle has a frequency distribution. The EVTGEN program simulates this quantum mechanical probability distribution by using a random number generator and an "acceptance/rejection" method. The missing mass histogram may display a peak, or "reflection," corresponding to the mass at a preferred angle, falsely suggesting a particle signature. If the

suspect peak is a “reflection” of the D_s^* and π system, then the mass plot’s jagged top should have a peak at 2620 MeV.

The decays we are examining can be traced within the deterministic model of the Monte Carlo, but are too swift for BaBar to detect in real life. The B^0 decay into a D^{*-} and a D_s^{*+} are impossible for BaBar to directly detect because the daughter particles are so unstable that they decay ridiculously quickly. BaBar can, however, reconstruct some of the other particles and their decays by examining the final products and trajectories. In the decay that interests us, the D^{*-} in turn decays into a charged charm meson resonance D^{*-} and a neutral pion π [2]. In the Monte Carlo, this decay of $D^{*-} \rightarrow D^{*-} \pi^0$ occurs with a 10% probability [1]. BaBar can recognize the D^{*-} particle by its decay mode into a neutral D^0 and a slow moving negative pion [2]. The D^{*-} and the D^0 particle have only a slight mass difference, liberating only enough energy to produce the π^- with small kinetic energy [2]. We are also interested in the decay tree of particles cascading from the anti- B^0 , which is exactly the same as the decay tree listed above except that all the signs of charges are reversed.

In this paper will examine the mass histogram background generated by the $B^0 \rightarrow D^{*-}$ D_s^{*+} with $D^{*-} \rightarrow D^{*-} \pi^0$ to see if it can account for the BaBar data’s observed peak at 2620

MeV. We will use the EVTGEN program, the PAW program, the GeneratorsQA package, and the Monte Carlo data set.

MATERIALS AND METHODS

The PEP-II collider's energy is specifically calibrated to produce B and B bar pairs of low kinetic energy, which then rapidly decay through a tree of unstable particles. Each particle detected at BaBar can be expressed as a reconstructed momentum 4 vector [1]. The first three components are the orthogonal 3 dimensions of the reconstructed momentum, while the fourth component is the particle's measured energy [1]. The energy E is the square root of the sum of the squared mass of B meson and the square of the momentum 3 vector [1].

$$P_{\text{recon}} = (\mathbf{p}_{\text{recon}}, E)$$

$$E = (\mathbf{p}_{\text{recon}}^2 + m_B^2)^{1/2}$$

Unlike the BaBar detector set, the Monte Carlo data set, although its writers used some quantum mechanical concepts to determine probabilities, specifies each particle and step of the decay tree. So while the real BaBar data must be examined and reconstructed backwards from its final products to its earlier stages, the Monte Carlo can be examined and sorted from its initial stages down to its final products. By altering the .dec file in Anders Ryd's EVTGEN package, we forced the B^0 to decay to a D^{*-} and a D_s^{*+} with a 100% frequency. We did not, however, alter the decay selecting file to force the anti- B^0 to decay to the D^{*+} and a D_s^{*-} , instead allowing the anti- B^0 to decay according to the probabilities coded into the Monte Carlo. We then wrote a loop into a heavily modified C++ code borrowed from the GeneratorsQA

library to catch all the decays to a charged D^* , wrote an interactive program to sift through all the progeny of the decay tree in case an intermediate particle state hid the charged D^* from the loop, and calculated the missing mass and the momentum unaccounted for by the charged D^* . Finally, we used PAW to construct histograms of the missing mass of the particles recoiling against the charged D^* .

By conservation laws, the momentum 4 vectors of all the progeny within the first two decay steps, D_s^{*+} , D^{*-} , and the neutral pion, should sum to the B's momentum 4 vector. We plotted the mass of the matter recoiling against the D^{*-} and expected to see a peak at the sum of masses of the D_s^{*+} and the neutral pion. The recoil or “missing” mass, expressed as the square of its momentum 4 vector, will be equal to the square of the difference between the B and the D^{*-} momentum 4 vectors

RESULTS

Figure 1 displays data collected from the BaBar detector [1]. Art Snyder fitted this histogram of roughly 700 events with a fourth degree polynomial and four Gaussian functions to display the peaks. The peak at 2620 MeV caught my mentor's eye and prompted this investigation. The error bars are very large because this decay is relatively rare in BaBar.

Figure 2 shows the MC histogram of mass recoiling from progeny D^{*+} in a cascade from an anti- B^0 . This appears to be a typical “missing mass” plot because we have not forced any decay modes.

Figure 3 shows the error bars for Figure 2. The error range is very small because the tuple of anti- B^0 parents cascading to particles that recoil against the D^{*+} contains roughly 40,000 relevant events.

Displayed in Figure 4 is the MC histogram of mass recoiling from the progeny D^{*-} cascaded from a B^0 . This plot is very different from the histogram of D^{*+} progeny from an anti- B^0 parent because we forced the decay mode $B^0 \rightarrow D^{*-} D_s^{*+}$ to a 100% probability within the Monte Carlo.

Figure 5 shows the error bars for Figure 4. The error bars are still pretty good, but not nearly as small as the error bars for the parent anti- B^0 histogram. The parent B^0 tuple only uses roughly 10,000 events, one fourth as many as the parent anti- B^0 tuple.

DISCUSSION AND CONCLUSION

We didn't force the anti- B^0 cascade to decay to the D^{*+} and D_s^{*-} , so we had expected a typically shaped histogram of missing mass. We expected peaks at the masses of the most common D_s particles, 1970 and 2110 MeV [2]. We also expected the typical background of irrelevant particles and noise in the plot of the missing mass. This background should slope upward as the particles get heavier, but should drop off dramatically when the combined energy and mass of the D^{*+} and the recoil particle reach a maximum available in a B decay. Figures 2 and 3 confirm that expectation.

The missing mass plot for the B^0 , however, should be more interesting. As expected, the edges of the parent B^0 missing mass plot drop off sharply, the width dictated by the trajectory angle's effect on the system mass. More importantly, the top of the mass plot in Figures 4 and 5, though jagged, lacks a peak at 2620 MeV. The lack of a peak means that the suspect peak in the BaBar data cannot be explained as a reflection of the D_s^* and π system. This finding eliminates the possibility that the peak is a reflection of that specific system, but it could still be a peak of

another decay and system. Fortunately, the C++ code used for this experiment can be easily modified to test further reflection possibilities. Since the completion of this D^{*-} experiment, Snyder has written a spin off copy of the code to see whether the 2620 MeV peak could be a reflection of the decay $B^- \rightarrow D_{s1}^-(2536) D^0$, finding he could eliminate this possibility.

The peak at 2620 is not necessarily a reflection. After a couple more years of data collection from BaBar, the peak could subside, meaning that it was only ever a statistical fluctuation. Further investigation entirely separate from this experiment could even reveal that the peak is not a reflection at all, or even a statistical fluctuation, but a new particle. That hypothesis and experiment, however, is out of the scope of this paper.

ACKNOWLEDGMENTS

I am grateful to the U.S. Department of Energy and to the Stanford Linear Accelerator Center for the opportunity to participate in the SULI program during the summer of 2003 and for the chance to observe and learn so much. I especially want to thank my mentors Arthur Snyder and Steve Wagner for their patience, persistence, advice, and knowledge. I also thank Mandeep Gill for his assistance and humor.

REFERENCES

- [1] Snyder, A., “Bump hunting in missing mass,” BAD#724, July 24, 2003
- [2] “The European Physical Journal C,” Springer-Verlag Heidelberg, Germany, 2000.

Figure 1: Histogram of ~ 700 BaBar events of mass recoiling against a charged D^* [1]

Figure 2: Monte Carlo background. $\sim 40,000$ events of mass recoiling against a D^{*+} in an anti- B^0 cascade.

Figure 3: Error bars in the Monte Carlo events of mass recoiling against a D^{*+} within a cascade from an anti- B^0 particle.

Figure 4: PAW histogram of $\sim 10,000$ Monte Carlo events. B^0 is forced to decay to D_s^{*-} and D_s^{*+} . Only mass recoiling against the D_s^{*-} is selected for this graph. The forced decay ensures that we are looking at the D_s^{*+} pion system.

Figure 5: Error bars for the B^0 cascade histogram of mass (consisting of the D_s^{*+} pion system due to the forced decay in the .dec file) recoiling against the D^{*-} .