An Exploration of Analysis Software at SLAC through the Study of X(3872)

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ABSTRACT

An exploration of analysis software at SLAC through the study of X(3872). ANDREW FISCHER (Harvey Mudd College, Claremont, CA, 91711) VALERIE HALYO (Stanford Linear Accelerator Center, Menlo Park, CA, 94025)

X(3872), a particle discovered by Belle Labs, has not yet been described in a sufficient enough way by any group to draw definitive conclusions about it. In order to verify the claims of Belle Labs and learn more about X(3872), Stanford Linear Accelerator Center (henceforth SLAC) has undertaken a project to analyze the particle, a subgroup of the BaBar project. The computing systems involved are complex; the tutorials for the software and new software releases both need constant testing and revision. Using a new software release, I tested tutorials for various software used by the BaBar group, including UNIX, Root, and CM2, in an effort to eventually analyze X(3872) data. The offline workbook for the BaBar software needs to be better maintained, and the CM2 tutorials need to be modified and updated. While none of my results contributed directly to the project (i.e. I have no results that add to information about X(3872)), improvement of the tutorials will streamline integration of new scientists into the BaBar group.

INTRODUCTION

Until recently, only particles with two (mesons) or three (baryons) quarks had been recognized. These particles and their energies are well explored and documented; they are described by the theory of quantum chromo-dynamics (QCD). QCD allows for more exotic particle resonances, however, such as five-quark states called pentaquarks, four quark meson-meson molecules, and other exotic states. My computing projects at SLAC aided research into the properties of the mysterious $X(3872)$.

$X(3872)$, a particle recently discovered by Belle Labs, is something of a mystery. No group can say how it functions with certainty. Many people believe it is a four quark $D-D^*$ molecule, while yet others believe that it is simply a higher charm resonance of another more mundane particle. While the nature of $X(3872)$ is uncertain, its decay modes are not. It decays readily into a J/ψ and ω , each of which further decays into easily detectible particles.

This paper contains a detailed discussion of the theory behind $X(3872)$, as well as a record of my efforts to contribute to the analysis of data collected on each particle by reviewing tutorials on a new BaBar software package, and a critique of that software. Information on this particle will contribute to our understanding of Quantum Field Theory (QFT) and Quantum Chromo-Dynamics (QCD), advancing our knowledge of physics. Software testing will facilitate tutorial writing and help scientists new to the BaBar system become familiar with its idiosyncrasies more easily.

MATERIALS AND PROCEDURE

X(3872) Theory

In studying X(3872), we must first understand when the particle is created and how it decays. The process that occurs in the accelerator is (see Fig. 1 for greater detail):

$$\begin{array}{c} e^+e^- \rightarrow X(3872) + \text{other} \\ | \\ \rightarrow J/\Psi + \omega \\ \begin{array}{cc} | & | \\ | & \rightarrow \text{daughters} \\ \rightarrow \text{daughters} & \end{array} \end{array} \quad [4]$$

The electrons and positrons in the accelerator annihilate to create the X(3872), which rapidly decays into other particles, namely the J/Ψ and ω . To detect X(3872), we choose decay modes for J/Ψ and ω , selecting daughter particles to look for in the detector. Ultimately, a weighted combination of highest-probability and easiest-to-detect decay modes should be what we use to find J/Ψ and ω , which we can then trace back to X(3872).

The highest-probability decay mode for ω is (see Table 1 for more information):

$$\omega \rightarrow \pi^+\pi^-\pi^0, 89.1 \pm 0.7 \% [3].$$

While J/Ψ has an identical decay mode, it only occurs about 1% of the time – the contribution of the J/Ψ to $\pi^+\pi^-\pi^0$ counts is insignificant. The highest-probability decay modes for J/Ψ are (see Table 2 for more information):

$$e^+e^-, 5.93 \pm 0.10 \%,$$

$$\mu^+\mu^-, 5.88 \pm 0.10 \% [3].$$

Since ω does not readily decay to leptons, these decay modes will indicate that J/Ψ is the particle in question. Leptons are also easily detected by the BaBar system, which makes this decay mode more attractive.

Each event that registers a pair of leptons and a $\pi^+\pi^-\pi^0$ triplet will now be included for analysis. Each event traces the track of the particle back to its point of origin, indicating where its mother particle was. Once we gain information on the J/Ψ and ω mother particles in each event, we can use information on their angular distribution, mass, momentum, and other attributes to discover information on X(3872).

Software Testing

The actual process I used to test information about the X(3872) involved familiarizing myself with BaBar software and other analysis tools. Unix, Linux, Root, CM2, and EMACS, were all foreign to me, so I had to learn to use them.

I spent the first week becoming accustomed to the operating system and beginning BaBar's offline workbook, a new user's first introduction to the BaBar system. The second week I finished the workbook and began to run tutorials in root, filling a histogram with Gaussian and double-Gaussian functions and fitting curves to them. From there, I began modifying the CM2 tutorial MyMiniAnalysisJob.tcl to run on a new test release. I created my own file as well, PracticeAnalysis.tcl, and ran that. With four weeks left, I began my final analysis project – to skeletonize and modify MyK0Analysis.tcl to run information on a J/Ψ .

RESULTS

The single and double Gaussian curve fits I created could not be sufficiently reformatted, and are thus not included in this paper. Another curve from an analysis tutorial is included as Fig. 2. The Gaussians were fit to histograms filled using random generators weighted by the single and double Gaussian functions.

No other histograms of interest or significant meaning were produced during my trials with the tutorials.

DISCUSSION

The online workbook [5] is somewhat frustrating for people completely unfamiliar with a UNIX environment. It is written at a level higher than I was capable of understanding completely, and contains information that is interesting but unnecessary for a new user to acclimate themselves to a new software system. In particular, if I could not understand a command then there was no easy way to get more information on it. The workbook assumes a new user already understands how the many software modules (Root, Kanga, CM2, etc.) all fit together and are nested within one another, so it never makes it explicitly clear.

The tutorials available on the Root website [6] are very helpful. They include complete code which is well commented, and can be experimented with to help determine what each function argument does.

CM2's tutorials were frequently frustrating. MyMiniAnalysisJob.tcl came with no data skim, so it would not work until I replaced it. The process of harvesting data from the database was challenging itself, because I was using a new test release that my mentor was unfamiliar with, and therefore the commands to gather data were challenging to find. Since the only data useful for my project concerned J/Ψ , but MyMiniAnalysisJob.tcl scanned for unrelated particles, all of the histograms were empty.

My attempt to create my own .tcl analysis file was unsuccessful – I duplicated the content of MyMiniAnalysisJob.tcl and renamed it “PracticeAnalysis.tcl”, replacing all file linking references with appropriately named PracticeAnalysis references. Neither Valerie nor I could understand why this file would not run, so we gave up on this file.

At this point, my time was dedicated to modifying another file, MyK0Analysis.tcl to be compatible with my test release, including J/Ψ and ω analysis information, and trying to make it run. In this stage of testing the inefficacy of the CM2 tutorials was shown more explicitly. The code I was including was completely mysterious to me, as was the code in the tutorial file. All my attempts to create histograms with J/Ψ information or even change the output of the tutorial file in any way were unsuccessful.

CONCLUSION

Unfortunately, I can make no conclusions about the X(3872). No information I gathered during my experimentation with the tutorials was helpful in discerning anything about the X(3872). I can, however, discuss the value and efficiency of the BaBar tutorials.

The offline workbook needs to be better maintained and reviewed for simplicity. It is the first thing a new user reads to become familiar with the BaBar system, and as such should be written with more detail (about appropriate topics), and include information on how to get more specifics on a confusing command.

The information available on UNIX and EMACS from the web was sufficient to run those programs, but this requires the new user to be proficient in finding such information out on their own. Links to approved tutorials or more information included in the offline workbook would be helpful.

The CM2 tutorials should be entirely redone. There is no way to understand what is going wrong if the file won't run, and the tutorial files are incomplete (the packages are missing data skims, for example). Each tutorial file should also have a version compatible with multiple software releases.

Additionally, all of these tutorials should be much better maintained. While searching for better information on a few questions, I found information with a timestamp of 1997 that was still accurate and information with a timestamp of 2002 that was well out of date. Keeping track of what information is useful and what is not will help save time for new users.

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- [6] <http://root.cern.ch/root/Tutorials.html>

TABLES AND FIGURES

<u>ω</u>	Width: 8.44 ± 0.09 MeV Mass: 782.57 ± 0.12 MeV
Highest probability ω Decay Modes: $\omega \rightarrow \dots$	Probabilities

$\pi^+\pi^-\pi^0$	$89.1 \pm 0.7 \%$
$\pi^0\gamma$	$8.7 \pm 0.4 \%$
$\pi^+\pi^-$	$1.7 \pm 0.28 \%$

Table 1: ω decay modes (probability>0.1%), width, and mass [3]

J/Ψ	Width: 87.5 ± 0.5 KeV Mass: 3096 ± 0.04 MeV
Highest probability J/Ψ Decay Modes: J/Ψ → ...	Probabilities
e^+e^-	$5.93 \pm 0.10 \%$
$\mu^+\mu^-$	$5.88 \pm 0.10 \%$
$2(\pi^+\pi^-\pi^0)$	$3.37 \pm 0.26 \%$
$3(\pi^+\pi^-\pi^0)$	$2.9 \pm 0.6 \%$
$\pi^+\pi^-\pi^0$	$1.50 \pm 0.2 \%$
$\gamma\eta_c$	$1.3 \pm 0.4 \%$
$P\pi$	$1.27 \pm .09 \%$
$\pi^+\pi^-\pi^0 K^+K^-$	$1.20 \pm 0.3 \%$
$A_2(1320)\rho$	$1.099 \pm 0.22 \%$

Table 2: J/Ψ decay modes (probability>1%), width, and mass [3]

Fig. 1: A more detailed drawing of the decay process of X(3872)

Fig. 2: Sample output from one of many root tutorials I ran