MONTE CARLO METHODS FINAL PROJECT ABSTRACT

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1. INTRODUCTION AND BACKGROUND

In high-energy physics, the annihilation process $e+e- \longrightarrow e+e-$ provides a clean and well-understood setting to study the properties of narrow resonances such as the J/ψ and $\psi(2S)$ [1]. When the center-of-mass energy of the incoming electron–positron pair approaches the mass of one of these bound states of charm quarks, the cross section exhibits a sharp enhancement: the resonance curve. This peak in the scattering probability reflects the formation of the intermediate vector meson, which subsequently decays back into leptons or hadrons.

The total observed cross section in such processes is governed by several key contributions, the main ones being: the Breit-Wigner resonance curve, the background Bhabha scattering, and first-order Initial State Radiation (ISR) corrections [2]. In this project I will be limiting myself to the in-depth study of these three effects and how they combine to produce the resulting curve.

2. MOTIVATION

While analytic expressions exist for the Breit–Wigner resonance and the ISR radiator function, realistic measurements are further complicated by finite energy resolution, detector acceptance, and statistical fluctuations. Direct theoretical calculations provide the baseline, but they do not fully capture the variability and uncertainties of an actual measurement.

Monte Carlo simulations are therefore an essential tool in this context. By stochastically generating events that incorporate ISR, detector smearing, and finite statistics, one can reproduce the expected line shapes under realistic conditions. This allows us to test analytic predictions against simulated "pseudo-data," study the influence of each effect in isolation, and develop intuition about how the clean theoretical resonance curve translates into what an experiment would observe.

From a pedagogical perspective, implementing such a simulation is an ideal final project for a Monte Carlo methods course: it combines fundamental high-energy physics with statistical modeling, numerical integration, sampling techniques from different probability density functions, and several convolutions. In general, this project should require a deep understanding of the topics discussed during the course.

3. GOALS

The goal of this project is to develop a simulation framework for resonance scans across the J/ψ and $\psi(2S)$ regions that incorporates all relevant physical effects. Specifically, I aim to:

- Generate pseudo-data for $e+e- \longrightarrow e+e-$ scattering near the resonances, including Breit–Wigner peaks, Bhabha background, and ISR distortions using Monte Carlo techniques.
- Model detector effects such as energy resolution and acceptance cuts.
- Compare simulated pseudo-data with theoretical predictions obtained from analytic convolutions.
- Create an easy-to-use simulation with variable parameters to test different experimental setups.

Ultimately, the objective is to achieve close agreement between Monte Carlo pseudo-data and theoretical curves, thereby validating both the analytic and stochastic approaches to resonance line shape modeling while demonstrating proficiency with the topics discussed in the course.

4. REFERENCES

[1] Burton Richter, "From the psi to charm - the experiments of 1975 and 1976," Dec 1976.

[2] V. P. Druzhinin, S. I. Eidelman, S. I. Serednyakov, and E. P. Solodov, "Hadron production via," *Reviews of Modern Physics*, vol. 83, no. 4, pp. 1545–1588, Dec 2011.