Experimental Techniques in Hadron Spectroscopy

Wouter Deconinck

UNIVERSITY OF MICHIGAN

Introduction
In hadron spectroscopy the distribution of the invariant mass $M$ is commonly used to determine the energy and width of hadronic resonances. For events that satisfy the selection criteria defined by the physical process under study (e.g. particle identification, vertex separation) the invariant mass of the resonant state is calculated from the four-momenta and the rest masses of the detected decay products. In the figures below the distributions for the hyperon decays $Y \rightarrow \Lambda \pi$ (left panel) and $A(1520) \rightarrow \pi \pi$ (right panel) are shown using events collected at the H1Rt experiment [1] on the HERA electron collider at DESY, Germany.

Advantages of Event Mixing

The large number of possible combinations grows as $n^2$, where $n$ is the number of events. Even for a small number of detected events the background shape can be determined with an almost arbitrarily high statistical precision (at the expense of computing time).

Imperfections of Event Mixing

When the mixing method is applied to the $A(1520)$ hyperon, the shaded distributions in the figure below are obtained. In the left panel the event mixing method is applied in its most simple form (shaded). The disagreement motivated several improvements.

Event Selection Criteria
- Single-track selection criteria, such as particle identification or momentum selection.
- Multiple-track selection criteria that combine the information of several tracks, such as vertex positions or the distance between two tracks.

Event Mixing

An entirely different approach to determining the background distribution is the method of event mixing [2,3]. When the detected events are limited to different regions of phase space from different events are combined as if they were from the same, events resonances and more generally all statistical correlations will be removed from the final mixed event distribution. In the figure below this is illustrated schematically for two events.

Mixed Resonance Events

The mixed event method is based on the assumption that the background distribution is identical before and after event mixing. However, when resonance events are mixed with each other they do not reproduce the background distribution but rather a different mixed resonance distribution.

The effect of the mixed resonance distribution can be demonstrated using Pythia Monte Carlo simulations. In the figures below the simulated invariant mass distributions for the hyperon decay $\Lambda \rightarrow \pi \rho$ are shown. Before event mixing the A hyperon resonance (in red) is clearly visible above an uncorrelated background of pT-pair creation disruption physical process. After event mixing the shape of this background distribution is unchanged, but the mixed resonance events (in green) are smeared out with a different shape than the background distribution. In the inset the original resonance shape and the mixed resonance distribution are compared.

In the figure on the left actual events collected at the H1Rt experiment are shown before (in black) and after event mixing (in green). The mixed event distribution overestimates the background shape consistent with the contribution from the combinatorial events. This is demonstrated in the inset where the difference (black points) is compared with the mixed resonance distribution from the Monte Carlo simulation (in green).

Momentum Mismatch

When events are mixed, the four-momentum vector of the replaced track is generally different from the original values. Uncommon or even unphysical combinations of the four-momentum vectors are disproportionately populated during the event mixing. This momentum mismatch distorts the mixed event invariant mass distribution. Tracks with similar four-momentum can be selected using a buffer with a sufficiently large size.

Summary

The widely-used experimental technique of determining resonance parameters from invariant mass distributions by fitting a smooth background function and Gaussian peak has been refined. This method of event mixing can be improved to obtain better approximations. Acceptance effects can still influence the shape of the observed resonance and should be taken into account.

Acknowledgements

I would like to thank my colleagues in the HERMES Collaboration for the many suggestions and useful discussions, in particular Wolfgang Lorentzen and Aytek Aiparbac who contributed many ideas. This research is supported by the U.S. National Science Foundation, Intermediate Energy Nuclear Science Division under grants PHY-0244842 and PHY-0554223.

References


This work was completed with support from