Development of the framework for the partial-wave analysis in the PANDA experiment

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Introduction

The PANDA Experiment will be one of the key experiments at the Facility for Antiproton and Ion Research (FAIR) which is under construction and currently being built on the area of the GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt, Germany. The central part of FAIR is a synchrotron complex providing intense pulsed ion beams (from p to U). Antiprotons produced by a primary proton beam will then be filled into the High Energy Storage Ring (HESR) which collide with the fixed target inside the PANDA Detector. The PANDA Collaboration with more than 450 scientist from 17 countries intends to do basic research on various topics around the weak and strong forces, exotic states of matter and the structure of hadrons [1].

Hadron spectroscopy at PANDA

One of the main challenges of hadron physics is the search for gluonic excitations, i.e. hadrons in which the gluons can act as principal components. These gluonic hadrons fall into two main categories: glueballs, i.e. states where only gluons contribute to the overall quantum numbers, and hybrids, which consist of valence quarks and antiquarks as hadrons plus one or more excited gluons which contribute to the overall quantum numbers. The additional degrees of freedom carried by gluons allow these hybrids and glueballs to have J^{PC} exotic quantum numbers. In this case mixing effects with nearby qq states are excluded and this makes their experimental identification easier. The properties of glueballs and hybrids are determined by the long-distance features of QCD and their study will yield fundamental insight into the structure of the QCD vacuum. Antiproton-proton annihilations provide a very favourable environment to search for gluonic hadrons.

Another goal of the hadron spectroscopy at PANDA is the precise measurement of the charmonium spectrum. While all eight charmonium states below open charm threshold are known, the measurements of their parameters and decays is far from complete. Above threshold very little is known: on one hand the expected D- and F- wave states have not been identified, on the other hand the nature of the recently discovered X, Y, Z states is not known. At full luminosity PANDA will collect several thousand cc states per day. By means of fine scans it will be possible to measure masses with an accuracy of the order of 100 keV and widths to 10% or better. PANDA will explore

the entire energy region below and above the open charm threshold, to find the missing D- and F-wave states and unravel the nature of the newly discovered X, Y, Z states.
An understanding of the baryon spectrum is one of the primary goals of non-perturbative QCD. In the nucleon sector, where most of the experimental information is available, the agreement with quark model predictions is astonishingly small, and the situation is even worse in the strange baryon sector. The PANDA experiment is well suited for a comprehensive baryon spectroscopy programme, in particular in the spectroscopy of (multi-)strange and possibly also charmed baryons. The main tool for these studies in the partial-wave analysis.

Partial-wave analysis at PANDA

Partial Wave Analysis (PWA) is widely used in high energy experimental physics. It is a useful method for analyzing the correlation between the momenta of final state particles in order to determine the masses, widths and spin-parities of intermediate resonances. The basis of PWA is relativistic kinematics. By using the method of group representation and applying analysis techniques that exploit the symmetries of the system, the form of the decay matrix element can be changed to a new form where the angular-dependent part of the matrix element is expressed by a D-function, and the energy-dependent part is kept in a reduced matrix element. In this new form, the angular information of the decay matrix element is separated from the energy information. This property is quite useful in partial wave analysis, since the angular-dependence of the decay matrix contains the information of the spin-parity of the decaying particles, and the energy dependence of the decay matrix contains information about the interactions of its constituents, or pole positions of intermediate states. In the PWA technique, both the angular and energy information of the decay matrix are utilized, and the spin-parity and pole position of the resonance can be determined simultaneously.
The new analysis tool is being developed by the Mainz University to perform PWA in PANDA. This is the ComPWA analysis framework [2]. The framework is written in C++ and is designed to be modular, capable to use different minimizer packages and easily extendable to use different physics models and formalisms.
Several approaches to parametrize the scattering amplitudes exist to perform PWA. One of the most powerful ones is the approach developed by the Gatchina group, which is based on the moment operator expansion technique [3]. The goal of this project is to implement this formalism in scope of the ComPWA framework.

General research program

The student's task will include the development of a C++ library for the ComPWA framework, that will implement all necessary tools to use the so called covariant tensor formalism. It will include design of a set of classes that perform tensor operations, calculus and finally provide amplitudes for the the physical reaction.

A good knowledge of basics of quantum mechanics and tensor calculus and of C++ programming language is required.

References

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