EMC studies using the simulation framework of PANDA

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Received Day Month Year
Revised Day Month Year

The Anti-Proton ANihilation at DArmstadt (PANDA) experiment proposed at the Facility for Antiproton and Ion Research (FAIR) in Darmstadt (Germany) will perform a high-resolution spectroscopy of charmonium and exotic hadrons, such as hybrids, glueballs and hypernuclei. A highly intense beam of anti-protons provided by High Energy Storage Ring (HESR) with an unprecedented resolution will scan a mass range of 2 to 5.5 GeV/c².

In preparation for experiments with PANDA, careful and large-scale simulation studies need to be performed in the coming years to determine analysis strategies, to provide feedback for the design, construction and performance optimisation of individual detector components and to design methods for the calibration and interpretation of the experimental results. Results of a simulation for the Electromagnetic Calorimeter (EMC), built from lead tungstate (PWO) crystals and placed inside the Target Spectrometer (TS), are presented. The simulations were carried out using the PandaRoot framework, which is based on ROOT and being developed by the PANDA collaboration.

Keywords: Antiproton, charmed hybrid, PANDA.

PACS numbers: 13.25.Ft, 87.64.Aa, 01.50.hv

1. Motivation

With the PANDA experiment at FAIR in Darmstadt a high resolution hadron spectroscopy will be performed. The charmonium states partly discovered with existing $e^+e^-$ experiments will be measured with the PANDA with much higher resolution, which could not be achieved by $e^+e^-$ machines, but only via $\bar{p}p$ processes. The exotic hybrid and glueball states, predicted by lattice QCD, as well as $\bar{p}A$ collisions will be also investigated. The experimental setup of the PANDA project needs to be able to reconstruct predicted states and their decay channels with high precision. Both, charged and neutral decay products of resonances, have to be detected with very good spatial and energy resolutions. For this purpose, detailed simulations and a corresponding analysis of various physics channels are performed.

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In this paper, the decay of the \( h_c \) charmonium state via the following reaction is discussed:

\[
p + p \rightarrow h_c \rightarrow \eta_c + \gamma \rightarrow (\pi^0 + \pi^0 + \eta) + \gamma \rightarrow 7\gamma. \tag{1}
\]

This is an example of a neutral decay, which can be studied with PANDA. The PANDA detection system will be the perfect instrument for this, since it is highly compact, versatile and has a \( 4\pi \) coverage.

2. PANDA detection system and PandaRoot framework

The PANDA detection system is presented in the left picture in Fig. 1. It depicts the Micro Vertex Detector (MVD), Time Projection Chamber (TPC) and, alternatively, Straw Tube Tracker (STT), ElectroMagnetic Calorimeter (EMC), Cherenkov detector (DIRC), Muon detector (MUO), Time-Of-Flight (TOF), Drift Chambers (DC) and the Forward Calorimeter (FC). The EMC detector, placed inside the Target Spectrometer (TS), consists of the forward end-cap (FwEndCap), barrel (Barrel) and the backward end-cap (BwEndCap) and is shown in more detail on the right hand side in Fig. 1. This highly granulated calorimeter, built from \( \sim 16000 \) PWO crystals with the size of about \( 2 \times 2 \times 20 \text{ cm}^3 \) and \( 22 X_0 \) radiation length, was used to reconstruct the presented charmonium \( h_c \) from seven photons in the final state.

![Fig. 1. Left: The PANDA detection system. Right: The forward end-cap (FwEndCap), barrel (Barrel) and the backward end-cap (BwEndCap) of the EMC together with a beam pipe. Both pictures are modelled using the PandaRoot simulation and analysis framework.](image)

Reaction (1) has been simulated by using the EvtGen event generator which has been included inside the simulation and analysis framework of the PANDA, called PandaRoot. EvtGen, adapted for PANDA, was designed by BaBar and originally used for the simulation of the physics of the B meson decays. The Rho package was applied to reconstruct invariant masses of final-state and intermediate particles of Eq. (1). The simulation framework is based on the Virtual Monte Carlo concept,
which allows to perform simulations for different transport models without changing the user code or geometry description. The electronic response of the EMC crystals was simulated together with an optimised cluster reconstruction analysis. The EMC response has been compared and tuned to experimental data.

3. Analysis of the $\eta_c$ state

The two-photon invariant mass spectrum, as presented in the top panels in Fig. 2 shows a clear signals from $\pi^0$ and $\eta$ particles on top of a continuous combinatorial background. The spectrum was fitted using a Gaussian function representing signal together with the second order polynomial function, representing the background. A standard deviation, $\sigma$, of 6 MeV and 15 MeV was found for the $\pi^0$ and $\eta$, respectively. Pions and etas were selected by applying a windows of $3\sigma$ around the two peaks as indicated by the arrows in both panels. The $3\sigma$ cuts have been applied to reduce the huge combinatorial background. The bottom-left panel in Fig. 2 depicts the invariant mass of the $(\pi^0\pi^0\eta)$ system for which all two-photon candidates were used to identify $\pi^0$ and $\eta$ particles. The bottom-right panel depicts the same analysis with the cuts applied to identify $\pi^0$ and $\eta$ mesons. Note that the peak to background ratio drastically improved by a factor 2500, as expected. The combination of the reconstructed $\eta_c$ mass, together with the remaining photon, provides the
Fig. 3. The invariant mass of the charmonium $h_{c}$ state, reconstructed from seven photons in the final state from the decay channel (1). The solid line represents the spectrum obtained using GEANT3 while the dashed line represents a simulation using GEANT4.

identification of the $h_{c}$ particle, as shown in Fig. 3. In this analysis, only cuts for $\pi^{0}$ and $\eta$ masses have been applied. The simulated spectrum representing the $h_{c}$, yields to a peak-to-background of 30, a mass resolution (FWHM) of 70 MeV, and an efficiency of the $h_{c}$ reconstruction of about 30%. The distributions predicted by the two transport models, GEANT3 and GEANT4, are comparable. A small shift of 25 MeV can be observed, which can originate from small differences in the energy response between GEANT3 and GEANT4. A further study is in progress.

4. Summary

The analysis of the charmonium $h_{c}$ state via the neutral channel has been done for two different transport models within the PandaRoot framework. A more extensive simulation for other channels, including charged particles, will be studied in the near future.

Acknowledgements

This research is supported by Veni-grant 680-47-120 from the Netherlands Organisation for Scientific Research (NWO), the University of Groningen and the Gesellschaft für Schwerionenforschung mbH (GSI), Darmstadt.

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