The Production of K^0's in p+p Reactions

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Abstract. We present the exclusive analysis of the reactions $p+p \rightarrow Y+\Delta^{++}/(p+\pi^+)+K^0$, where Y stands for the Λ or Σ^0 hyperon. The proton-proton measurement was performed with the HADES setup at GSI, Darmstadt, at a kinetic beam energy of 3.5 GeV. A dedicated sideband technique allows to reproduce the non-strange background and its kinematics in the selected data sample. Therefore, it is possible to obtain the background subtracted missing mass distribution MM($p\pi^+\pi^+\pi^-$), where we can separate the Λ from the Σ^0 channel. From a Monte Carlo simulation of possible reactions we see contributions also by the reactions $p+p \rightarrow \Sigma^+/\Sigma(1385)^+ + p + K^0$. The ongoing analysis should provide exclusive cross sections of the mentioned reactions and their angular distributions.

1. Introduction

The study of kaons in heavy ion collisions is of particular interest, as they are not absorbed by the surrounding medium and thus carry information about the most interesting high-density stage of the collision. Such reactions are commonly interpreted in view of transport models. In this context, cross-sections of kaon production in nucleon-nucleon collisions are needed as an input for these models. A review on this topic can be found in [1]. While the 3-body strangeness production (e.g. $p+p \rightarrow Y+p+K$ with $\mathrm{Y} = \Lambda, \Sigma$) is rather well studied in a wide energy range, 4-body reactions (e.g. $p+p \rightarrow Y+p+\pi+K$) are not that well known experimentally as well as theoretically. Especially for lower energies ($\sqrt{s} < 3.35$ GeV) only one measurement exists for the channel $p+p \rightarrow \Lambda+p+\pi^+ + K^0$ at $\sqrt{s} = 2.97$ GeV [2], but none for the analogous Σ^0 channel. At higher energies several bubble chamber experiments have been performed [3, 4, 5, 6]. All these experiments suggest considerable contribution from an intermediate Δ^{++} resonance, which decays to the measured p and π^+. Since the appearance of an intermediate resonance would modify the kinematics of its daughter particles, it is necessary to quantify its contribution and extract informations about the dynamics of such a reaction. These considerations motivate our study of the exclusive channels $p+p \rightarrow Y+\Delta^{++}/(p+\pi^+)+K^0$ at $\sqrt{s} = 3.18$ GeV. Besides, our data provides informations on the reactions $p+p \rightarrow \Sigma^+ + p + K^0$ and $p+p \rightarrow \Sigma(1385)^+ + p + K^0$.

2. The Experiment

The **H**igh-**A**cceptance **D**i-**E**lectron **S**pectrometer (HADES) is a fixed target experiment located at GSI Hemholtzzentrum in Darmstadt (Germany). The beam is delivered by the SIS18 synchrotron, which can be heavy ions of 1-2 AGeV or protons up to 3.5 GeV kinetic beam energy. The detector setup covers almost the full azimuthal range, while the acceptance in the polar angles reaches from 18° to 85° degrees. The momentum resolution is Δ p/p $\approx$ 3%.

The most important components for the current analysis are following: Four layers of Multiwire-Drift-Chambers (MDCs) deliver together with the superconducting magnet (toroidal field) informations on the particle momentum. Furthermore, particle identification is possible knowing additionally the energy loss in the MDCs. A Time-Of-Flight wall at the end of the setup allows for online triggering. Here, the LVL1 trigger required at least three hits (M3) in this Time-Of-Flight wall to reduce contributions from elastic reactions.

In this report, we discuss the measurements performed in collisions of a proton beam with 3.5 GeV kinetic energy on a liquid hydrogen target. In total, 1.14×10^9 events have been collected.

3. Exclusive Analysis

As already mentioned, it is important to understand the production of strangeness in elementary nucleon-nucleon processes. One of the uncertainties here are the contributions of resonances, which can change the dynamics of a reaction. Therefore, this exclusive analysis focuses on reactions containing a K^0 in the final state associated with an intermediate $\Delta(1232)^{++}$ resonance. In the end, the goal is to extract the cross sections of the exclusive channels and to determine angular distributions, which can serve as an input or as a check for transport models.

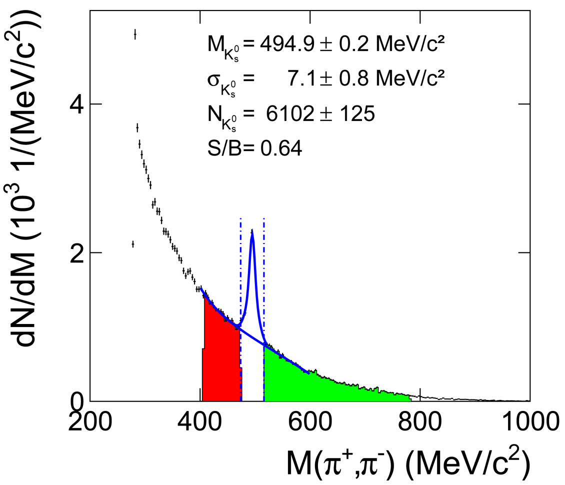

Figure 1. Invariant mass of a (π^+,π^-) pair after secondary vertex cuts for the selected event sample. The blue dashed-dotted lines show the three σ region around the K^0_S signal. The red and green area indicate the chosen low and high mass sideband sample respectively.

3.1. Event selection

The main channels that are investigated are $p+p\rightarrow\Lambda/\Sigma^0+p+\pi^++K^0$, where the short-lived component K^0_S is reconstructed via its decay into π^+ and π^-. The event selection has been chosen such as to enhance events with these reactions in the analysed data set, namely by selecting events with exactly the four charged particles proton, π^+, π^+ and π^-, which are identified with the energy loss information from the MDCs. This way the data sample will also include contributions from further reactions like $p+p\rightarrow\Sigma^++p+K^0$ and $p+p\rightarrow\Sigma(1385)^++p+K^0$, which need to be considered. As we are only interested in reactions with a K^0_S in the final state, we introduce a cut on the $\pi^+\pi^-$-invariant mass. The resulting distribution is shown in figure 1 after applying the following off-vertex cuts to decrease combinatorial background: (1) distance between the two pion tracks ($d_{\pi^+-\pi^-}<7$ mm), (2) distance between the primary reaction vertex and the secondary decay vertex ($d(K^0_S-V)>25$ mm), (3) distance of closest approach to the primary vertex for the two pion tracks ($\mathrm{DCA}_{\pi^+}>7$ mm, $\mathrm{DCA}_{\pi^-}>7$ mm). This invariant mass spectrum is fitted with the sum of two Gaussians for the signal and a polynomial and a Landau function for the description of the background. A three σ cut around the K^0_S signal is then used for further analysis, where σ is the averaged standard deviation of the two Gaussians.

3.2. Background Determination

As can be seen in figure 1 considerable background contribution is left under the K^0_S signal. This background mainly comes from the remaining contribution of non-strange reactions in our data sample, for example $p+p \to p+\pi^+ +\pi^+ +\pi^- +n$ or $p+p \to p+p+\pi^+ +\pi^+ +\pi^- +\pi^-$ and many others. A good description of this background is necessary. Therefore, a dedicated sideband analysis has been developed. For that we explicitly define a sample of background events by selecting two-track combinations having a $(\pi^+\pi^-)$-invariant mass in the mass region adjacent to the K^0_S signal. This sample is marked as red and green areas in figure 1 as low and high mass sample, respectively. To obtain a correct description of the background remaining after the K^0_S mass cut, the kinematics of this background has to be reproduced by the sideband sample. That means the momentum distribution of the K^0_S background needs to be modeled. To find this distribution, a cut on the missing mass $\mathrm{MM}(p\pi^+\pi^-) < 1100$ MeV/c^2 has been applied to reject all channels with a K^0_S in the final state. By simultaneously fitting the momentum distributions of the low and high mass sample to the one of the K^0_S background, we can determine the relative contribution of both sideband samples. The result of this fit is depicted on figure 2, where the magenta histogram corresponding to the sum of low and high mass sample is compared to the K^0_S background in black. One can see a very good description of the background kinematics.

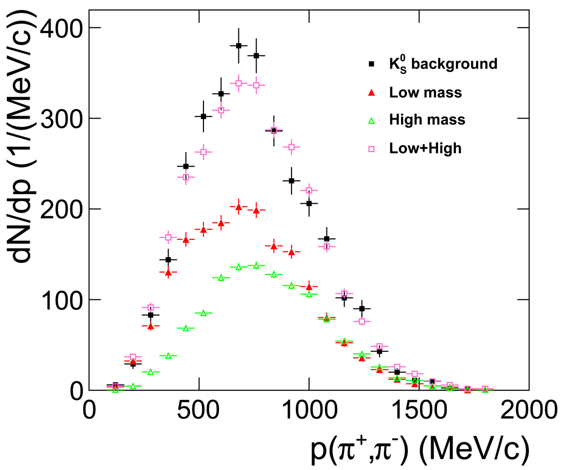

Figure 2. Momentum distribution of the K^0_S background. Applied cuts are a three σ cut around the K^0_S peak in the $\mathrm{IM}(\pi^+\pi^-)$, and a cut on $\mathrm{MM}(p\pi^+\pi^-) < 1100$ MeV/c^2. Relative weights of low mass and high mass sideband samples were extracted from a fit. The sum of both is shown in magenta.

3.3. Reaction Separation

As mentioned above this analysis focuses on the reactions $p + p \to \Lambda/\Sigma^0 + p + \pi^+ + K^0$. The only difference is the associated hyperon. Thus, one can plot the missing mass $\mathrm{MM}(p\pi^+\pi^+\pi^-)$, which should show two peaks at the Λ and the Σ^0 mass. Figure 3 illustrates this missing mass distribution with the following conditions: The cut on the K^0_S has been applied; additionally, a cut was used on the missing mass $\mathrm{MM}(p\pi^+\pi^-) > 1270$ MeV$/c^2$ to reject the channel $p + p \to \Sigma^+ + p + K^0$; the background as defined in the last section was subtracted. From the remaining missing mass distribution we see a clear Λ and Σ^0 peak, which allows us to distinguish between both contributions. The plotted coloured curves in the same figure are Monte Carlo simulations of the mentioned K^0 production channels. Some weakly contributing K^0 production channels like $p+p \to p+n+K^+ + \bar{K}^0$ are summed up and referred to as "other K^0_S channels". To this end, all channels have been simulated with isotropic angular distributions except for the $p+p \to \Sigma(1385)^+ +p+K^0$ and the $p+p \to \Sigma^+ +p+K^0$ reactions. For the first reaction we assume the same anisotropy as extracted for the reaction $p+p \to \Sigma(1385)^+ +n+K^+$ in the same data set [7]. For the Σ^+ reaction the anisotropy was adopted from [8] as found at $p_{beam} = 3059$ MeV$/c$.

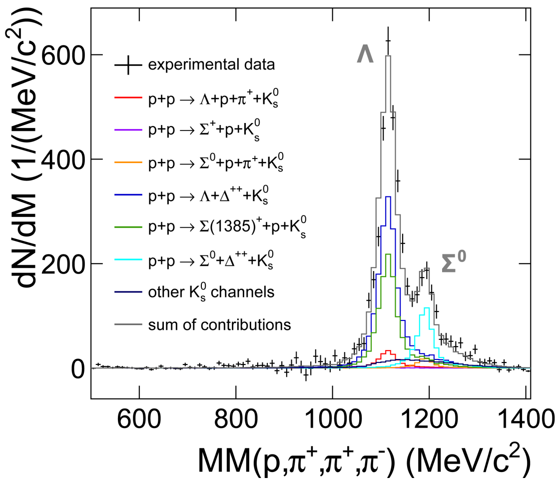

Figure 3. Missing mass of a (p,π^+,π^+,π^-) track combination with a cut on MM($p\pi^+\pi^-$) $>$ 1270 MeV/c^2 after K^0_S preselection. The background is subtracted using the sideband sample. The grey histogram corresponds to the sum of simulated contributions.

4. Summary and Outlook

This report has shown that from the selected data sample of 4-body reactions we are able to model the non-strange background via a sideband analysis. This allows us to study the remaining K^0 production channels, mainly the reactions $p+p \to \Lambda+p+\pi^++K^0$ and $p+p \to \Sigma^0+p+\pi^++K^0$ to extract their contribution. Here we want to determine the contribution of an intermediate Δ^{++} by studying the invariant mass of p and π^+. Different kinematics are expected for these channels. Additionally, we can study the channels $p + p \to \Sigma(1385)^+ + p + K^0$ and $p + p \to \Sigma^+ + p + K^0$, which are also present in the selection. These channels are expected to exhibit anisotropic prodution. While our simulations take this into account, a quantitative study of the angular distributions of the Δ^{++} reactions remains an open issue, which are expected to show anisotropic behaviour as well. We have also shown that a separation of these two reactions is possible by cutting on the Λ or the Σ^0 mass in the missing mass distribution MM($p\pi^+\pi^+\pi^-$). Finally, one can extract the cross sections of the exclusive reactions by fitting all the simulated K^0 channels to relevant experimental observables. These information can then serve as an input for transport models or used to cross-check the available calculations.

Acknowledgment

The authors gratefully acknowledge the support of the TUM Graduate School's Faculty Graduate Center Physics at Technische Universität München, Germany, LIP Coimbra, Coimbra (Portugal) PTDC/FIS/113339/2009 SIP JUC Cracow, Cracow (Poland) N N202 286038 28-JAN-2010 NN202198639 01-OCT-2010 FZ Dresden-Rossendorf (FZD), Dresden (Germany) BMBF 06DR9059D TU Mnchen, Garching (Germany) MLL Mnchen DFG EClust 153 VH-NG-330 BMBF 06MT9156 TP5 GSI TMKrue 1012 NPI AS CR, Rez, Rez (Czech Republic) MSMT LC07050 GAASCR IAA100480803 USC - S. de Compostela, Santiago de Compostela (Spain) CPAN:CSD2007-00042 Goethe-University, Frankfurt (Germany) HA216/EMMI HIC for FAIR (LOEWE) BMBF:06FY9100I GSI F&E.

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