PROCEEDINGS OF SCIENCE

Proton-proton and Lambda-proton correlations measured in p+Nb collisions at 3.5 GeV with HADES

Oliver Arnold for the HADES collaboration*
Physik Department E12, Technische Universität München, 85748 Garching, Germany
Excellence Cluster 'Origin and Structure of the Universe', 85748 Garching, Germany
E-mail: oliver.arnold@mytum.de

We present a two-particle correlation analysis of proton- and Λp-pairs, measured with the HADES detector in p+Nb reactions at a kinetic beam energy of 3.5 GeV. The proton-proton correlation function is used to extract the source size of the pNb system. Using this information together with a UrQMD transport simulation we are able to fix the Λp source size and reduce the number of parameters. With this approach we are able to test different predictions of scattering parameter. We tested scattering length and effective ranges from chiral effective field theory. It is shown that the Λp correlation function develops a sensitivity on different sets of scattering parameters.

54th International Winter Meeting on Nuclear Physics
25-29 January 2016
Bormio, Italy

*Speaker.

PoS(BORMIO2016)028

1. Introduction

The general picture of two-particle correlations is that there is a finite probability that particles emitted from a source after the freeze-out can still interact among each other. Such interactions show up in two-particle correlation functions in the momentum space for low relative momenta of the particle pair under investigation. Knowing the final state interactions and symmetries between the particles one is able to extract the size of this emission region. However, it is also possible to turn the picture around: by knowing the radii of the particle emitting source one is able to investigate the final-state interaction of the pair. This is in particular interesting for pairs where the interaction is not well established. This is mainly the case for strange hadrons like pairs of $p\bar{\Lambda}, \Lambda\Lambda, p\Xi$. In most of these cases there is, if any, information from scattering experiments and therefore any data about the interaction is helpful in this respect. A couple of successful analyses using this technique were already performed with extractions of interaction parameters like cross sections, scattering length and effective ranges [1] [2] [3].

2. The HADES Experiment

2.1 The individual components

The High-Acceptance Di-Electron Spectrometer (HADES) is a fixed target experiment located in Darmstadt, Germany, at the GSI Helmholtzzentrum für Schwerionenforschung. Originally designed to measure rare electromagnetic decays of vector mesons like ω, ϕ, ρ into dilepton pairs, the detector setup is also able to measure hadrons with an average momentum resolution of $\Delta p/p \approx 3\%$. Collision systems studied with HADES span a wide range, from elementary $p+p$ collisions up to more complex heavy-ion reactions of $Au+Au$, but also experiments with pion beams were performed quite recently to investigate e.g. excitations of N^* resonances. HADES covers a nearly full azimuthal range of 85% and a polar angle interval between 18° and 85°.
HADES consists of several detector components which can be used for particle identification. We will present only these components which are used for the analysis. The superconducting magnets located between the Multiwire-Drift-chambers (MDCs) provide the momentum and polarity of the particles. The MDCs measure the energy loss of the traversing charged particles. This information together with theoretical Bethe-Bloch curves allows to identify the particles in a first step. In a second step we use additionally the energy loss measurement of the Multiplicity and Electron Trigger Array (META) system, which consists of two Time-Of-Flight walls named TOF and TOFINO, which have different time resolutions and polar angle coverages.

2.2 The collision system under investigation

The HADES collaboration measured in 2008 the collision of a proton with a niobium nucleus (p$+^{93}$Nb), where the kinetic energy of the proton was $E_{\mathrm{kin}} = 3.5$ GeV. This pA system offers the interesting environment to study particle productions and correlations between them in a rather low energy regime (compared to LHC or RHIC), which gives us the possibility to try to find similarities and trends which are already well established in heavy-ion reactions at large energies.

3. Data Analysis

As have been already mentioned, on the one hand the femtoscopy method can be used to study the size of the region of homogeneity, on the other hand by knowing the radii of the emitting source one can use this information to study final-state interactions. Because of this reason, the analysis was divided into two parts. In the first part we investigated the properties and size of the source by using proton-proton pairs, because the interaction is well established and a lot of pairs are produced in the pNb reaction. Additionally, it's a baryon pair like Λp in which we are interested to study its interaction, performed in the second part of the analysis. To connect both parts transport simulations were performed using the UrQMD transport model [4]. UrQMD provides the information of the point of the last interaction of the particles and with this information the source functions for pp and Λp can be calculated. This helps to get an independent measure of the Λp source size which was fixed to study solely effects of different sets of scattering parameters on the correlation function.

3.1 Proton-Proton correlation function

To identify protons, we use the energy loss information of the MDCs and the META system. With this method we obtain a proton sample which has a global purity of about 99%. The experimental correlation function is calculated by using pairs from the same event and divide them by a pair distribution obtained from mixed events. The correlation function is investigated as a function of the relative momentum of the pair in their rest frame $k = \frac{1}{2}|\mathbf{p}_1 - \mathbf{p}_2|$, $\mathbf{p}_1 + \mathbf{p}_2 = 0$. The idea is that pairs from event mixing reproduce the kinematics of the particle production but by construction are free from femtoscopic two-particle correlations. The experimental correlation function suffers from several detector efficiencies. First of all, correlated particles are usually emitted close together in space, which means the opening angle between the pair is small. This leads to the problem that at some point the opening angle is so small, that because of the finite granularity of the components, the detector is not able to distinguish between two pairs anymore. This leads to the well known track merging effect. Because the mixed event sample contains by construction always two distinct tracks, the track merging introduces a suppression of the correlation signal. We correct for this effect by looking at the ($\Delta\phi$, $\Delta\Theta$) plane, where a clear suppression for same events is visible. We exclude this angle region from the sample to get rid of the close track suppression. As a next step we explore the finite momentum resolution of the detector. A finite resolution usually leads to a broadening of the correlation signal which leads to an underestimation of the extracted source sizes. We simulate this effect by creating an ideal and a smeared mixed event distribution with the UrQMD event generator [4]. The smeared sample is obtained by simulating also the detector response of HADES. With this procedure the effect of the finite momentum resolution on the correlation function can be studied. As a last step, we had to deal with additional correlations present in the data. Usually the correlation signal is located at small relative momenta $k < 100$ MeV/c. Above this momentum region the particles are not correlated anymore in terms of femtoscopy effects and the correlation function should approach unity. Because we have to deal with a small pA system ($\langle A_{\text{part}} \rangle = 2.7$) additional correlations are present and the baseline of the correlation function is still rising with increasing momenta. This effect can be explained by energy and momentum conservation which is not completely reproducible with the mixed event sample.

To get rid of this so called long range correlations (LRC) we use the UrQMD event generator (for pp correlations) and GiBUU [5] (for Λp correlations), where the events are free from any femtoscopic correlations. The model are able to describe the LRC of the correlation function and follows exactly the same trend. This motivates the introduction of a new correlation measurement defined as $C_{\mathrm{LRC-free}} = C_{\mathrm{meas}}/C_{\mathrm{UrQMD}}$. After applying all the corrections we compare the measured correlation function to the theoretical prediction obtained by the Koonin-Pratt formalism [6]. The model takes the quantum statistics of the fermion pair into account and their Coulomb and strong interactions. For the source function we assume a Gaussian shape, which is very common in femtoscopy analyses and obtain a preliminary Gaussian source size of $R^{pp}_{G,meas} = 2.02 \pm 0.01(\mathrm{stat})$ fm.

3.2 Λp correlation function

To obtain the Λp correlation function we use only the energy loss information from the MDCs for particle identification. This way we don't loose statistic with further PID cuts. The Λ-hyperon is reconstructed via the p,π^- invariant mass ($\Lambda \to p+\pi^-$,BR $\sim 64\%$) technique. To reduce the combinatorial background of p,π^--pairs, which do not originate from Λ decays, we employ certain topological cuts. To explore the systematics of these cuts on the correlation function we test three different cut combinations which give different Λ purities of $P^{\Lambda}_{1,2,3} = 86.1, 89.6$ and 92.5%. The correlation function is corrected for close track efficiency, momentum resolution, purity and LRC. To study sets of scattering parameters we used the UrQMD model. With this simulations, which include also the information of the freeze-out coordinates, we are able to determine the source functions and their sizes of the pp and Λp system. UrQMD predicts an about 20% smaller source size for Λp, which results in a ratio of $\mathrm{RF} = R^{pp}_{G,UrQMD}/R^{\Lambda p}_{G,UrQMD} = 1.18$. Together with the proton-proton measurement $R^{pp}_{G,meas}$ we are able to fix the source size of the Λp pair. With help of the the Lednicky-Lyuboshitz model [7] we are able to test different predictions of scattering length and effective ranges. We used predictions from chiral effective field theory [8], which predicts two sets of scattering parameter sets from leading order (LO) and next-to-leading order (NLO). It was shown that the correlation function is sensitive to these two different sets of scattering parameters.

References

[1] Adamczyk L *et al.* 2015 *Phys. Rev. Lett.* **114** 022301

[2] Kisiel A, Zbroszczyk H and Szymanski M 2014 *Phys. Rev.* C **89** 054916

[3] J. Adamczewski-Musch *et al.* 2016 *Phys. Rev.* C **94** 025201

[4] Bass S A *et al.* 1998 *Prog. Part. Nucl. Phys.* **41** 255

[5] O. Buss *et al.* 2012 *Phys.Rept.* 512 1-124

[6] Koonin S E 1977 *Phys.Lett.* B70 43-47

[7] Lednicky R and Lyuboshitz V L 1982 *Sov. J. Nucl. Phys.* **35** 770

[8] J. Haidenbauer *et al.* 2013 *Nucl. Phys.* A 915 24-58