

Two-particle correlation measurements in p+**Nb** reactions at $\sqrt{s_{\text{NN}}} = 3.18$ GeV

Oliver Arnold^{1,2} for the **HADES** collaboration

¹ Physik Department E12, Technische Universität München, James-Franck-Str. 1, 85748 Garching, Germany

² Excellence Cluster 'Origin and Structure of the Universe', Boltzmannstr. 2, 85748 Garching, Germany

E-mail: oliver.arnold@mytum.de

Abstract. We present a two-particle correlation measurement of proton- and of 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 size of the region of homogeneity. Using this information together with a UrQMD transport simulation opens the possibility to study the interaction of Λp pairs in terms of spin average scattering length and effective range.

1. Introduction

The collision of two heavy nuclei at high energies creates a complex system, which is believed to undergo several evolution steps in time including e.g. a hydrodynamic expansion controlled by the viscosity of the system. At the end of the time evolution, the formed hadrons freeze out and fly into the detector setup. To gain information about the underlying physics of the multi-particle production and the system dynamics, it is helpful to investigate the correlations between the produced particles. Measuring two-particle correlations between particles emitted from a source at freeze-out provides information about the spatio-temporal extension (radii) of the region of homogeneity on the femtometer scale. A dependence of these radii e.g. on the transverse mass m_T of the pair is sensitive to various properties like the time scale of the evolution.

The general picture of two-particle correlations is that there is a probability that particles leaving the source after the freeze-out can still interact among each other. Knowing the final state interactions between the particles, one can solely concentrate on extracting the radii. 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 especially between particle species where the interaction is not well determined. This is mainly the case for strange hadrons like pairs of $p\bar{\Lambda}$, $\Lambda\Lambda$ etc.. 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].



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 $\Delta p/p \approx 5\%$. 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), which information is also part of the tracking procedure, 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 META system, which consists of two Time-Of-Flight walls named TOF and TOFINO, which distinguish themselves by 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 ($p + {}^{93}\text{Nb}$), where the kinetic energy of the proton was $E_{\text{kin}} = 3.5$ 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. A further advantage of the rather low energy is that the measured correlation function is free from correlation-disturbing effects induced for example by mini-jets, which can mimic a femtoscopy signal in the interesting region of low relative momenta and the absence of many high mass resonances which contribute via their feed down to residual correlations.

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.

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 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 any other 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, which 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 some 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 [3]. The smeared sample is obtained by simulating also the detector response of HADES. Both samples are weighted with a correlation weight, and the parameters of the weight are chosen in a way that the smeared correlation function matches the experimental measurement. Because we know also the ideal momenta we can correct for the momentum smearing. As a last step, we also have to deal with a more difficult effect that can be observed 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 assume that the correlation signal and the LRC signal factorize because they stem from completely different sources $C_{\text{meas}} = C_{\text{femto}} \times C_{\text{LRC}}$.

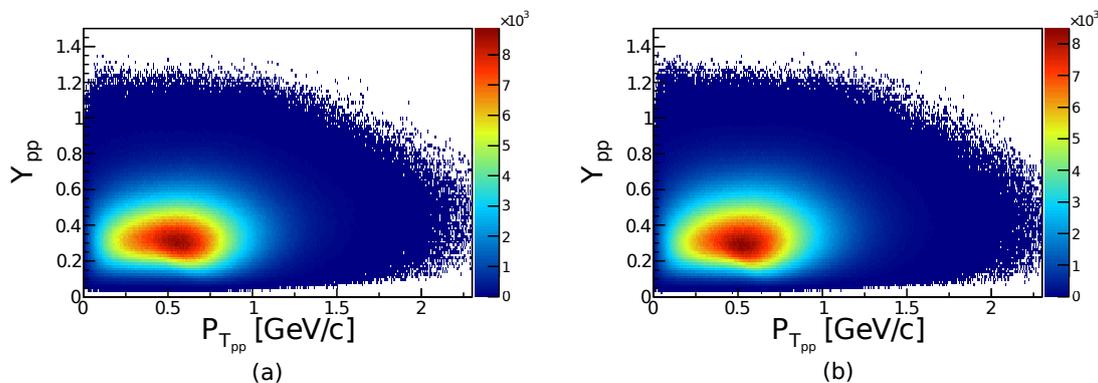


Figure 1. Two-particle phase-space of proton pairs as a function of the total transverse momentum and total rapidity inside of the HADES acceptance. The plot on the left side (a) is for experimental data and the right one (b) for simulations using the UrQMD model. The distributions look very similar, which means that UrQMD is able to describe the kinematics of the pairs.

To simulate the LRC, we use the UrQMD event generator, where the events are free from any femtosopic correlations. The kinematics of the model is in good agreement with the experimental data which can be seen in Figure 1 illustrating the two-particle phase-space of protons as a function of the total transverse momentum and total rapidity of the pair in the HADES acceptance. The model is also 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 $C_{\text{LRC-free}} = C_{\text{meas}}/C_{\text{UrQMD}}$. After applying all the corrections we compare the measured correlation function to the theoretical prediction obtained by the Koonin-Pratt formalism [4]. 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 $R_{G,\text{meas}}^{pp} = 2.016 \pm 0.010_{-0.027}^{+0.039}$ fm including errors from statistics, momentum resolution and close track rejection.

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 lose statistic with further PID cuts. The Λ -hyperon is reconstructed via the p, π^- invariant mass ($\Lambda \rightarrow p + \pi^-$, BR $\sim 64\%$) technique. To reduce the combinatorial background of p, π^- -pairs, which do not originate from Λ decays, we employ topological cuts on certain track parameters: A cut on the flight distance of the Λ , a cut on the distance between the daughter tracks, a cut on the distance of the daughter tracks to the primary vertex, and a cut on the pointing angle between the Λ momentum vector and the vector pointing from the primary to the secondary vertex. To explore the systematics of these cuts on the correlation function we test three different cut combinations which give different Λ purities of $P_{1,2,3}^\Lambda = 86.1, 89.6$ and 92.5% . An example plot showing the invariant mass distribution for the first cut combination is given in Figure 2. For all three topological cut combinations we

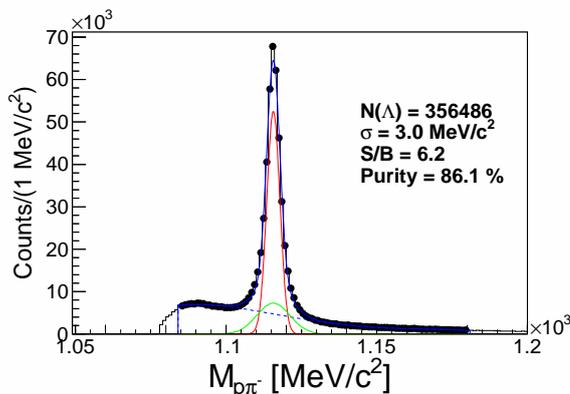


Figure 2. Invariant mass of p, π^- pairs for one certain topological cut combination.

calculate the Λp correlation function and obtain the positive correlation signal, which is expected due to the attractive interaction between Λp . All three correlation functions are corrected for close track efficiency, momentum resolution, purity and LRC. With help of UrQMD 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, where UrQMD predicts an about 20% smaller source size for Λp , which results as a ratio of RF = $R_{G,\text{UrQMD}}^{pp}/R_{G,\text{UrQMD}}^{\Lambda p} = 1.23$. Together with the proton-proton measurement $R_{G,\text{meas}}^{pp}$ we are able to fix the source size of the Λp pair. By fitting the Lednický-Lyuboshitz model [5], which depends on the scattering lengths and effective ranges, to the data we are able to extract spin averaged values for the scattering length and effective range.

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

[4] Koonin S E 1977 *Phys. Lett. B* **70** 43

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