Abstract. The space-time evolution of the source of particles formed in the collision of nuclei can be studied through particle correlations. The STAR experiment is dedicated to study ultra-relativistic heavy ions collisions and allows to measure non-identical strange particle correlations. The source size can be extracted by studying $p-\Lambda$, $\bar{p}-\bar{\Lambda}$, $p-\Lambda$ and $p-\bar{\Lambda}$ correlation functions. Strong interaction potential has been studied for these systems using an analytical model. Final State Interaction (FSI) parameters have been determined and has shown a significant annihilation process present in $\bar{p}-\Lambda$ and $p-\bar{\Lambda}$ systems not present in $p-\Lambda$ and $\bar{p}-\bar{\Lambda}$.

Keywords: interferometry, non-identical particles, Final State Interaction

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1. Introduction

Non-identical particles are correlated due to final state Coulomb and nuclear interactions \cite{1}. Contrary to $p-\Lambda$ \cite{2,3,4}, the nuclear FSI (Final State Interaction) of $\bar{p}-\Lambda$, $p-\bar{\Lambda}$ and $\bar{p}-\bar{\Lambda}$, is still unknown. In this paper, data from the STAR experiment are shown and the Lednický & Lyuboshitz model \cite{5} is used to analyse experimental correlation functions \cite{6}. The STAR detector (a Solenoid Tracker At RHIC), installed at RHIC (Relativistic Heavy Ion Collider), allows the reconstruction of the particles produced during the Au+Au collisions at 200 GeV per nucleon pair in the center of mass.
2. Experimental correlation functions

The particles are measured in Au-Au collisions at \( \sqrt{s_{NN}} = 200 \) GeV using the Time Projection Chamber (TPC). Central events accounting for 10% of the total cross section are selected.

The relevant variable is the momentum of one of the particles in the pair rest frame called here \( \vec{k}^* \). The non-correlated background is constructed by mixing events with primary vertex separated from each other by less than 10 cm. The correlation function has been extracted by constructing the ratio of two distributions. The numerator is the \(|\vec{k}^*|\) distribution of pairs from the same event. The denominator is the \(|\vec{k}^*|\) distribution of pairs from mixed events.

Protons and anti-protons are selected using their specific energy loss (dE/dx). This selection limits the acceptance of particles to the transverse momentum range of 0.4-1.1 GeV/c in the rapidity interval \(|Y| < 0.5\).

Lambdas (anti-lambdas) are reconstructed through the decay channel \( \Lambda \rightarrow \pi + p \) (\( \bar{\Lambda} \rightarrow \pi + \bar{p} \)), with a corresponding branching ratio of 64%. Pions and protons are selected using their specific energy loss. In addition some geometrical cuts are applied, giving a lambda/anti-lambda purity sample of 86%, the remaining 14% representing the combinatorial background. Only lambdas/anti-lambdas in the rapidity range \(|Y| < 1.5\) are selected. Due to the acceptance of the detector, the transverse momentum range is 0.3-2.0 GeV/c.

The contamination and the feed-down have been studied in order to estimate the purity (Eq. (1)) of \( p, \bar{p}, \Lambda \) and \( \bar{\Lambda} \) as a function of the transverse momentum \( (p_t) \). The purity is defined as the product of the probability of identification (Pid) multiplied by the fraction of primary particles (Fp).

\[
Purity(p_t) = \text{Pid}(p_t) \times \text{Fp}(p_t) \tag{1}
\]

The probability of identification has been estimated as a function of \( k^* \) for charged particles. Identified protons (anti-protons) from the selected sample account for 76.5 \( \pm \) 2% (74 \( \pm \) 2%). For lambdas (anti-lambdas) the probability of identification correspond to the signal over noise value, it is independent of \(|\vec{k}^*|\): 86.54 \( \pm \) 0.04% (86.13 \( \pm \) 0.04%).

The feed-down estimation has been done for \( p, \bar{p}, \Lambda \) and \( \bar{\Lambda} \) as a function of the transverse momentum \( (p_t) \) in order to take into account the \(|\vec{k}^*|\) dependence of the purity. Combined results from STAR [11, 12, 13, 14, 15, 16] and predictions from the thermal model [10] have been used. The approximations done by estimating the purity, raise the problem of considerable uncertainties on extracted values for FSI parameters and radii.

The calculated feed-down leads to an estimated purity of 54% for primary protons \( (< p_t > = 0.70 \text{ GeV/c}) \). Most of the secondary protons come from lambda decay and represent 35% of the protons used to construct the correlation function. Other sources of contamination of protons are provided by decay products of \( \Sigma^+ \) and pions interacting with matter, which represent respectively 10% and 1% of the sample.
The feed-down study for anti-protons \((< p_t > = 0.73 \text{ GeV/c})\), leads to an estimated purity of 56% for primary anti-protons. Most of the secondary anti-protons come from anti-lambda decay and represent 32% of the anti-protons used to construct the correlation function. For anti-protons, the additional source of contamination, which is the decay product of \(\Sigma^+\), represents 12%.

The sample of lambdas (anti-lambdas) includes secondary particles such as decay products of \(\Xi, \Xi^0, \Sigma^0 (\Xi, \Xi^0, \Sigma^0)\). The fractions of lambdas \((< p_t > = 1.20 \text{ GeV/c})\) and anti-lambdas \((< p_t > = 1.23 \text{ GeV/c})\) coming from the primary vertex have been estimated at 44%.

The pair purity plays a crucial role in the correlation study. The estimated value of the pair purity for \(p-\Lambda, \bar{p}-\bar{\Lambda}, p-\bar{\Lambda}\) and \(\bar{p}-\Lambda\) systems is 15%. The contamination tends to reduce the correlation strength. Raw data has been corrected for purity using the following method:

\[
C_{true}(k^*) = \frac{C_{measured(k^*)} - 1}{\text{PairPurity}(k^*)} + 1
\]  

where PairPurity represents the product of the two value of purity of particles, \(C_{true}(k^*)\) represents the corrected correlation function and \(C_{measured(k^*)}\) represents the measured one.

![Fig. 1. The uncorrected measured \(p-\Lambda\) correlation functions. (a) \(p-\Lambda, \bar{p}-\bar{\Lambda}\) and their sum. (b) \(\bar{p}-\Lambda, p-\bar{\Lambda}\) and their sum.](image)

In addition, the effects of momentum resolution have been studied using mixed pairs and by calculating the weight with the Lednický & Lyuboshitz analytical
model. It appears that compared to statistical and systematic errors, the impact of the momentum resolution effect is negligible. Nevertheless, correlation functions have been corrected for the momentum resolution using the following formula:

$$C_{true}(k^*) = \frac{C_{measured}(k^*) \ast C_{Th-not-smeared}(k^*)}{C_{Th-smeared}(k^*)}$$  \hspace{1cm} (3)$$

where $C_{true}(k^*)$ represents the corrected correlation function.

The ratio $C_{Th-not-smeared}(k^*)/C_{Th-smeared}(k^*)$ is the correction factor, where $C_{Th-not-smeared}(k^*)$ is estimated without taking into account the effect of momentum resolution and $C_{Th-smeared}(k^*)$ includes effects of the momentum resolution.

The $p - \Lambda$, $\bar{p} - \bar{\Lambda}$ correlation functions and their sum are presented in Fig.11 (a). Fig. 11 (b) represents the $p - \Lambda$, $\bar{p} - \bar{\Lambda}$ correlation functions and their sum. The $p - \Lambda$ and $p - \bar{\Lambda}$ correlation functions, measured for the first time, appear to be negative.

3. Lednický & Lyuboshitz analytical model

The Lednický & Lyuboshitz analytical model uses the strong FSI for $p - n$ [5, 7] in the frame of the effective range approximation in order to calculate correlation functions. Since the only interaction between the two baryons is the strong one,
like $p$ and $n$, this model has been used to study experimental correlations [6].

The distribution of the relative positions is assumed to be gaussian:

$$r^2 \sim e^{-r^2/4r_0^2}$$  \hspace{1cm} (4)

$r_0$ being considered as the radius of the source. We consider that particles are not polarized. For $\bar{p} - \Lambda$ and $p - \bar{\Lambda}$, the spin dependence of the scattering length is neglected $f^S = f^T = f$, with $S$ and $T$ for singlet and triple states. The effective range $(d_0)$ is set to zero. These assumptions allow to better constrain fitted parameters. An extra parameter, $Im(f_0)$ (the imaginary part of the scattering length) should be introduced to take into account the baryon - anti-baryon annihilation channel. The fit parameters from [2] have been used for $p - \Lambda$, $\bar{p} - \Lambda$ correlation functions and for their sum to extract values of the radius $r_0$ (Table 1) after corrections for purity and momentum resolution. The extracted source parameters are close to values obtained in measurements performed by NA49 (CERN) collaboration in Pb+Pb collisions.

### Table 1. Parameters of $p - \Lambda$ and $\bar{p} - \Lambda$ interaction used to determine the radius of the source of particles.

| Systeme     | Parameter | Value |
|-------------|-----------|-------|
| $f_0^S$ (fm) | 2.88      |       |
| $d_0^S$ (fm) | 2.92      |       |
| $f_0^T$ (fm) | 1.66      |       |
| $d_0^T$ (fm) | 3.78      |       |
| $p - \Lambda$ | $r_0$ (fm) | 2.94 $\pm$ 0.34$^{+0.32}_{-0.45}$ |
| $\bar{p} - \Lambda$ | $r_0$ (fm) | 3.24 $\pm$ 0.59$^{+0.26}_{-0.14}$ |
| $p - \Lambda + \bar{p} - \Lambda$ | $r_0$ (fm) | 3.09 $\pm$ 0.30$^{+0.32}_{-0.14}$ |

### Table 2. Parameters extracted from $\bar{p} - \Lambda$, $p - \bar{\Lambda}$ and their sum.

| System     | Parameter | Value (fm) |
|------------|-----------|------------|
| $\bar{p} - \Lambda$ | $d_0$ (fm) | 0.0        |
| $\bar{p} - \Lambda$ | Im($f_0$) | $1.88^{+1.78}_{-1.89}$ |
| $\bar{p} - \Lambda$ | Re($f_0$) | $-2.82 \pm 1.28^{+1.18}_{-2.16}$ |
| $\bar{p} - \Lambda$ | $r_0$ | $1.56 \pm 0.07^{+0.07}_{-0.63}$ |
| $p - \Lambda$ | Im($f_0$) | $0.37^{+0.66}_{-0.26}$ |
| $p - \Lambda$ | Re($f_0$) | $-1.20 \pm 1.07^{+0.36}_{-0.54}$ |
| $p - \Lambda$ | $r_0$ | $1.41 \pm 0.10^{+0.07}_{-0.85}$ |
| $\bar{p} - \Lambda + p - \Lambda$ | Im($f_0$) | $1.01^{+0.92}_{-1.13}$ |
| $\bar{p} - \Lambda + p - \Lambda$ | Re($f_0$) | $-2.03 \pm 0.96^{+0.35}_{-1.12}$ |
| $\bar{p} - \Lambda + p - \Lambda$ | $r_0$ | $1.50 \pm 0.05^{+0.44}_{-0.92}$ |
collisions at 158 AGeV [3] and by the E895 (AGS) experiment in Au+Au collisions at 4, 6, and 8 AGeV [4]. In particular, using the correlation function allows to estimate the final state interaction parameters for the $p - \Lambda$ and the $p - \bar{\Lambda}$ systems (Table 2).

One can notice that the value of the imaginary part of the scattering length obtained for $p - \Lambda$ pairs (Table 2) is in agreement with the scattering length (0.8 fm) previously obtained for $p - p$ pairs spin averaged [5].

The source radius extracted from $p - \Lambda$ and $p - \bar{\Lambda}$ correlation functions, is smaller than the one extracted from $p - \Lambda$ and $p - \bar{\Lambda}$ correlation functions.

4. Conclusion

The $p-\Lambda$, $p-\bar{\Lambda}$, $p-\Lambda$, $p-\bar{\Lambda}$ correlation functions have been shown. Corrections for momentum resolution and particle purity have been taken into account. The pair purity has a stronger effect on the correlation function than momentum resolution and is an important source of systematic errors. These uncertainties have been included in the fit procedure to the parameters and taken into account as systematic errors. It has been shown that by studying $p-\Lambda$ and $p-\bar{\Lambda}$ one can estimate the size of the source of particles at freeze-out. Final state interaction parameters, such as the scattering length, can be extracted from $p-\Lambda$ and $p-\bar{\Lambda}$ correlation functions.

The negative shape of the $p-\Lambda$ correlation function is consistent with the one extracted for the symetric system, $p-\bar{\Lambda}$. The large range in $k^*$ of the correlation function is still not understood, and results in a very small value of the extracted radius.

References

1. R. Lednicky et al., Phys. Lett. B 373 (1996) 30
2. F. Wang, S. Pratt, Phys. Rev. Lett. 83 (1999) 3138
3. C. Blume for NA49 collaboration, nucl-ex/0208020
4. P. Chung for E895 collaboration, nucl-ex/0212028
5. R. Lednický & V. L. Lyuboshitz Proc. CORINNE 90 Nantes, France, 1990 (ed. Ardouin, World Scientific) p. 42
6. G. Renault for STAR collaboration, hep-ex/0404024
7. R. Lednický, nucl-th/0112011
8. B.O. Kerbikov et al, Nucl. Phys. A558 (1993) 177c
9. Particle Data Group [http://pdg.lbl.gov/]
10. P. Braun-Munzinger et al, Phys. Lett. B518 (2001) 41
11. J. Adams et al., nucl-ex/0306024
12. J. Adams et al., nucl-ex/0307024
13. C. Adler et al., Phys. Rev. Lett.89 (2002) 092301, nucl-ex/0203016
14. J. Adams et al., Multi-strange baryon transverse expansion in Au+Au collisions at $\sqrt{s_{NN}} = 200\text{GeV}$, to be published
15. J. Adams et al., Phys. Rev. Lett. 92 (2004) 112301, nucl-ex/0310004
16. M. A. C. Lamont, Ph.D Thesis, Neutral Strange Particle Production in Ultra-Relativistic Heavy Ion collisions $\sqrt{s_{nn}} = 130$ GeV (2002)