

Measurement of $\Lambda\Lambda$ spin correlations in the SELEX experiment

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Abstract. We study HBT interferometry of $\Lambda\Lambda$ pairs produced in Σ^-A interactions using a $\Lambda\Lambda$ spin composition measurement with data taken by SELEX, which accumulated data during the 1996–97 fixed target run at Fermilab. While the spin composition of a $\Lambda\Lambda$ pair in the range of four-momentum difference of a pair $Q < 1.5$ GeV was found to be consistent with the suppression of spin state one, for $Q > 1.5$ GeV it was found to be consistent with statistical spin mixture. For the $\Lambda\bar{\Lambda}$ system the spin one fraction was found to be consistent with the expectation for a statistical spin mixture. We also estimated the dimension of the $\Lambda\Lambda$ production region.

1. Introduction

HBT correlations of pairs of identical particles are sensitive to the size of the emission source. These correlations were found to originate from two-particle wave function properties: according to the Bose-Einstein (BE) statistics, production of identical bosons is enhanced and according to the Fermi-Dirac (FD) statistics, production of identical fermions is suppressed.

Currently data on Λ hyperons correlations is limited to the following experiments: ALEPH [1], OPAL [2], DELPHI¹ [3] in hadronic Z^0 decays produced in e^+e^- annihilation at LEP, NA49 [4] in Pb ions collisions and EXCHARM [5] in nC interactions.

In this paper we report preliminary results on a study of $\Lambda\Lambda$ spin composition using events obtained on Σ^- beam in the SELEX experiment. An estimation of the size of the $\Lambda\Lambda$ particle production region is presented. We compare our results to those obtained with the correlation function technique [6, 7] and with world results.

2. The method

2.1. Correlation function

FD and BE Correlations may be studied in terms of two-particle correlation function $C_2(Q)$ defined as follows:

$$C_2(Q) = \frac{P_{exp}(Q)}{P_{ref}(Q)} = \frac{N_{ref}}{N_{exp}} \cdot \frac{dN_{exp}(Q)/dQ}{dN_{ref}(Q)/dQ}, \quad (1)$$

¹ preliminary result

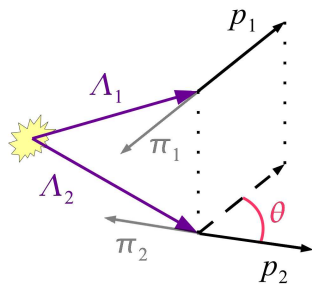


Figure 1. θ is determined as an angle between decay protons of $\Lambda\Lambda$ system, each of them is transformed to the parent hyperon rest frame.

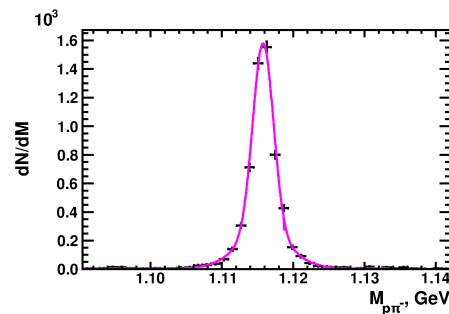


Figure 2. Effective mass of $p\pi^-$ for selected pairs. $M_\Lambda = 1115.7 \pm 0.4 \text{ MeV}/c^2$, $\sigma = 0.9 \text{ MeV}/c^2$.

where Q is the relative 4-momentum of a pair; P_{exp} — measured differential cross section of the pairs; P_{ref} — reference cross section of the pairs, which is free from FD or BE effects, but otherwise equal to the experimental sample; N_{exp} is the experimentally measured number of pairs and N_{ref} — number of pairs in the reference sample. Determination of the proper reference distribution is the major experimental challenge. Further details may be found in [1, 6].

For an estimation of the particle production source extent different parametrizations may be applied. The most commonly used is the Goldhaber parametrization [8], defined as follows:

$$C_2(Q) = N(1 + \beta e^{-R^2 Q^2}), \quad (2)$$

where N is a normalization constant, R — space-time extent of the source, β — suppression parameter.

2.2. Spin composition

Another way to study ($\Lambda\Lambda$) correlations is to determine the spin composition of the system [1, 9, 10]. Let us denote y^* as the cosine of the angle θ between decay protons of each parent hyperon (see figure 1). Each proton should be transformed to its hyperon rest frame. Taking into account P-violation at the Λ decay from Wigner-Eckart theorem [11] for the $\Lambda\Lambda$ system one obtains:

$$dN/dy^*|_{S=0} = N(1 - \alpha_\Lambda^2 y^*), \quad dN/dy^*|_{S=1} = N(1 + \frac{\alpha_\Lambda^2}{3} y^*). \quad (3)$$

where S is the spin of di-hyperon system, $\alpha_\Lambda = -\alpha_{\bar{\Lambda}}$ is Λ decay asymmetry parameter [12].

Lets define the fraction of the spin one contribution as ε , then from equation 3 one gets:

$$dN/dy^* = (1 - \varepsilon) dN/dy^*|_{S=0} + \varepsilon dN/dy^*|_{S=1} = N \left(1 + \left(\frac{4}{3}\varepsilon - 1 \right) \alpha_\Lambda^2 y^* \right). \quad (4)$$

Equation 4 was obtained for non-relativistic Q value, however, it was pointed out that the validity of this equation can be extended to any Q value [13].

Two-particle correlations functions $C_2(Q)$ for $S = 0$ and $S = 1$ states may be derived from equation 2 in order to estimate the particle production source size R using $\varepsilon(Q)$:

$$\varepsilon(Q) = \frac{C_2(Q)_{S=1}}{C_2(Q)_{S=0} + C_2(Q)_{S=1}} = 0.75 \frac{1 - \gamma e^{-R^2 Q^2}}{1 - 0.5\gamma e^{-R^2 Q^2}}, \quad (5)$$

where $\gamma = -2\beta$.

3. The SELEX experiment and data selection

3.1. Experimental setup

SELEX (E781) is the SEgmented LargE X_F baryon spectrometer — a fixed target (Cu, C) experiment with Σ^- , π^- and p beams with 600 GeV mean energy, from the Tevatron accelerator at FNAL. This experiment was dedicated for charm particles registration with high precision of the decay vertex coordinates and momenta of daughter particles. SELEX provides 10^9 trigger events used in this analysis. The E781 experiment is described in detail in paper [14]. In this report we rely mainly on the vertex spectrometer with $6.5 \mu m$ spatial resolution and on the RICH detector for particle mass identification.

3.2. Data selection and simulation

In this article we analyze Σ^- beam events, which constitutes 67.1% of the full experimental statistics. Λ ($\bar{\Lambda}$) hyperons were identified by $\Lambda \rightarrow p\pi^-$ ($\bar{\Lambda} \rightarrow \bar{p}\pi^+$) decays in inclusive reactions. Tracks were reconstructed using the SELEX Off-line Analysis Program, further processing was done using VBK and LaCor [15] software packages.

The most important cuts are described below:

- Only Λ hyperons which decayed in the vertex region were used because of the best decay vertex reconstruction.
- V^0 candidates with duplicated daughter tracks or segments of these tracks were excluded from the analysis.
- Daughter track momenta must satisfy the ratio $p_\pi/p_p < 0.5$.
- Distance of closest approach between tracks was required to be less than 0.015 cm.
- The angle between the Λ momentum and the Λ track should be less than 0.1 mrad.
- Λ sample was cleared from misidentified K^0 using the Podolansky-Armenteros distribution [16].

The total selected sample contains 3153 $\Lambda\Lambda$ pairs and 4608 $\Lambda\bar{\Lambda}$ pairs in the range $Q < 5$ GeV. The effective mass distribution of a $\Lambda\Lambda$ sample is shown on figure 2. A Sum of two gauss functions was used as a fit. There is negligible background. The reconstructed Λ mass $M_\Lambda = 1115.7 \pm 0.4$ MeV/ c^2 is in good agreement with world data [12]. The detector resolution is found to be $\sigma = 0.9$ MeV/ c^2 .

In order to obtain the acceptance correction, a Monte-Carlo simulation was performed using the PYTHIA-6.4 [17] generator. The full detector simulation was done using the GE781 package [18] (GEANT-3.21 tuned for E781 experiment). Further data processing was done in the same way as for experimental data.

The simulation process for a complicated setup such as E781 requires substantial computing power. Therefore not only the local ITEP farm was used, but GRID resources were utilized as well within the framework of the Photon virtual organization. $3 \cdot 10^9$ trigger event were simulated to reduce the contribution of statistical errors of simulated events to the final result error.

4. Results

In order to measure the spin composition $\varepsilon(Q)$ for the $\Lambda\Lambda$ system, experimental angular distributions dN/dy^* are build according to equation 4 for the range $Q < 4$ GeV. They are corrected for acceptance losses in the following way: $dN/dy^* = dN/dy_{exp}^* \frac{dN/dy_{gen}^*}{dN/dy_{det}^*}$, where dN/dy_{exp}^* — experimentally obtained angular distribution; dN/dy_{gen}^* — angular distribution after PYTHIA generator; dN/dy_{det}^* — angular distribution after full detector simulation using GEANT.

Corrected dN/dy^* distributions for $\Lambda\Lambda$ system are shown on figure 3 for the case of division of entire Q range into 4 intervals. Distributions were fit by the theoretical function from equation 4

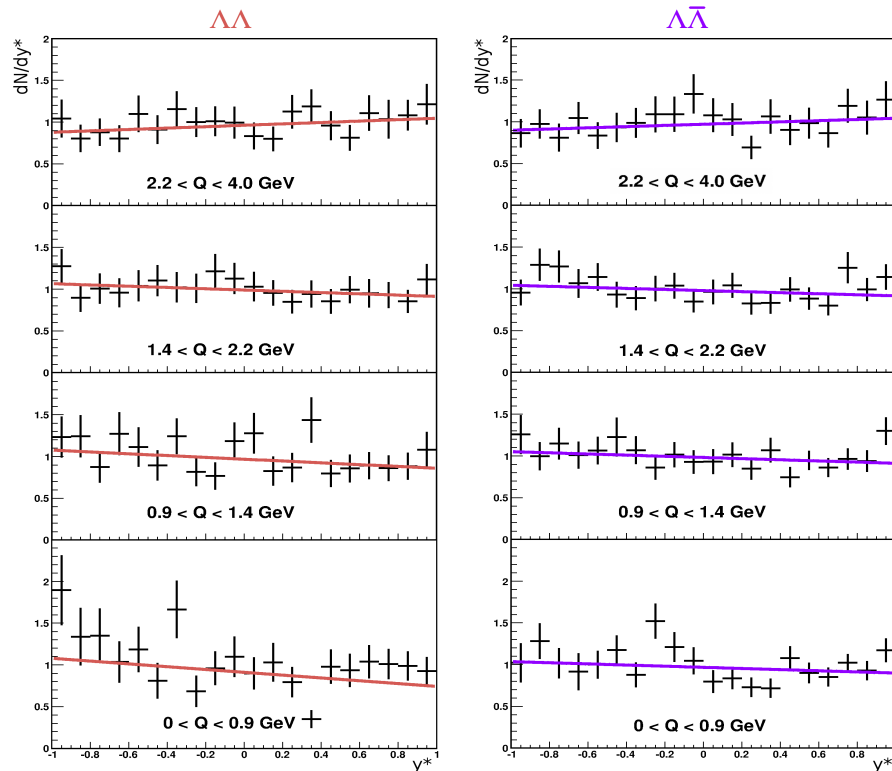


Figure 3. Corrected dN/dy^* distributions obtained for $\Lambda\Lambda$ and $\Lambda\bar{\Lambda}$ systems. The lines show fit by function provided in equation 4.

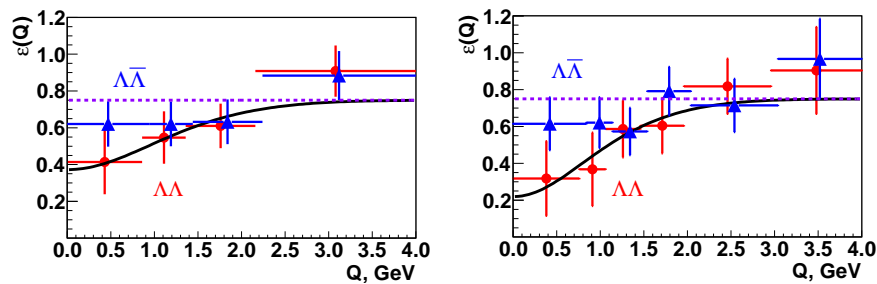


Figure 4. Spin one contribution $\varepsilon(Q)$ for $\Lambda\Lambda$ (\bullet) and $\Lambda\bar{\Lambda}$ (\blacktriangle) systems for different subranges selection. — represents a fit by equation 5, - - - represents statistical spin distribution.

to extract $\varepsilon(Q)$ values for each subrange. The $\Lambda\bar{\Lambda}$ system was analyzed as well (taking into account $\alpha_{\Lambda} = -\alpha_{\bar{\Lambda}}$) to check consistency with $\varepsilon(Q) \equiv 0.75$ for the spin one contribution to the system of non-identical particles.

The obtained $\varepsilon(Q)$ functions are shown on figure 4. In order to account for the systematic uncertainty caused by an arbitrary subinterval choose, $\varepsilon(Q)$ is obtained for 4 and 6 Q subintervals as shown on figure 4. A clear suppression of $S = 1$ state is seen for the $\Lambda\Lambda$ system for the range $Q < 1.5$ GeV, while the $\Lambda\bar{\Lambda}$ system remains consistent with statistical spin mixture.

To estimate the source extent R , a fit to equation 5 was applied. To account for further systematical errors, two alternative fit functions were used: the function from equation 5

with fixed $\gamma = 1$ parameter to take into account contribution of incoherent sources and an alternative parametrization proposed in [2]: $\eta(Q) = 0.75 \left(1 - \gamma e^{-R^2 Q^2}\right)$. The obtained fit parameters are given in table 1. n_Q is the number of bins chosen, γ — suppression parameter describing strength of correlations. The final result for the source size estimation is: $R_{spin} = 0.31 \pm 0.11_{stat} \pm 0.04_{syst}$ fm, it is in good agreement with the result obtained from correlation function analysis of the same data sample [7] of 3153 $\Lambda\Lambda$ pairs: $R_{C_2(Q)} = 0.203 \pm 0.034$ fm.

Table 1. The values of R obtained for different spin contribution functions and different chooses of Q subinterval.

n_Q	Fit	γ	R , fm	n_Q	Fit	γ	R , fm
4	$\varepsilon(Q)$	0.69 ± 0.24	0.33 ± 0.12	6	$\varepsilon(Q)$	0.83 ± 0.21	0.30 ± 0.10
		1.0_{fixed}	0.22 ± 0.08			1.0_{fixed}	0.26 ± 0.06
	$\eta(Q)$	0.51 ± 0.25	0.30 ± 0.11		$\eta(Q)$	0.68 ± 0.29	0.26 ± 0.08

5. Conclusions

A first measurement of the spin correlations in $\Lambda\Lambda$ and $\Lambda\bar{\Lambda}$ systems produced in $\Sigma^- A$ interactions is presented. As a preliminary result, a total sample of 3153 $\Lambda\Lambda$ pairs and 4608 $\Lambda\bar{\Lambda}$ was analysed. A clear suppression of the $S = 1$ state has been observed in the $\Lambda\Lambda$ system for $Q < 1.5$ GeV, while $\Lambda\bar{\Lambda}$ remains consistent with a statistical spin mixture. Estimation of the space-time extent of $\Lambda\Lambda$ production region gives: $R = 0.31 \pm 0.11_{stat} \pm 0.04_{syst}$ fm, which is in agreement with the result obtained from a correlation function analysis on the same data sample [7] of 3153 $\Lambda\Lambda$ pairs, and with measurements from ALEPH [1], OPAL [2], DELPHI [3] and EXCHARM [5] experiments.

Acknowledgments

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