Observation of Ω^- and $\overline{\Omega^-}$ in Sulphur-Tungsten Interactions at 200 GeV/c per Nucleon

The WA85 Collaboration

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Abstract

Multistrange baryon and antibaryon production is suggested to be a useful probe in the search for Quark Gluon Plasma formation. We report the detection of an $\Omega^- + \overline{\Omega^-}$ signal in central S+W interactions at 200 A GeV/c and measure the ratio $\overline{\Omega^-}/\Omega^- = 0.57 \pm 0.41$ at central rapidity and $p_T > 1.6$ GeV/c.

A new state of matter made of deconfined quarks and gluons, the Quark Gluon Plasma (QGP), is predicted to be created in central collisions of heavy ions at ultrarelativistic energies, to last for a few fm/c and to decay into hadrons. Strange particles are expected to be an important diagnostic tool in the search for the QGP since the onset of this new state would favour their production [1]. Enhancements of various strange particle species have indeed been observed in nucleus-nucleus interactions when compared to proton-proton and proton-nucleus interactions [2]. However, their interpretation as signatures for the QGP phase is not straightforward, since secondary interactions occurring in the large hadronic fireball created by the collision could produce a strange particle enhancement even in the absence of an initial QGP phase: given enough time for the fireball to achieve chemical equilibrium, the resulting enhancement could be similar to that expected from the decay of a QGP [3,4]. It has been suggested [5] that antihyperons can provide a way of distinguishing between the QGP and the hadronic rescattering scenarios since, unlike in the hyperon case, antihyperon production by rescattering is too slow a process to play an important role over the short lifetime of the hadronic fireball. In contrast both hyperons and antihyperons produced during the QGP hadronization could have abundances near chemical equilibrium values since chemical equilibrium is more easily achieved in a QGP because of the low $s\bar{s}$ pair production threshold [6]. A comprehensive study of the relative abundances of various hyperon and antihyperon species, for different projectile masses and energies, is therefore necessary in order to understand whether a QGP phase is produced. In this context the rare $\bar{\Omega}^-$ are of particular interest since their production by rescattering is even smaller than for $\bar{\Lambda}$ and $\bar{\Xi}^-$.

Experiment WA85 has already obtained results on the relative abundances of Λ , $\bar{\Lambda}$, Ξ^- and $\bar{\Xi}^-$ in S + W collisions at 200 A GeV/c [7,8,9,10,11]. In this letter we report the first observation of Ω^- and $\bar{\Omega}^-$ in nucleus - nucleus collisions and a measurement of the $\bar{\Omega}^-/\Omega^-$ production ratio at central rapidity ($2.5 < y_{\text{LAB}} < 3.0$) and medium transverse momentum ($p_{\text{T}} > 1.6$ GeV/c). The data come from the last (1990) run of the WA85 experiment; the sample consists of 60 million triggers, representing a sixfold increase in statistics over the sample used in [8]. The WA85 apparatus and the trigger to select central collisions ($\sim 30\%$ of the inelastic cross section) were the same as those used in the previous (1987) run and have been described elsewhere [10]. In this letter, whenever we indicate particles or decay channels we are also referring implicitly to the charge conjugate systems, unless otherwise obvious from the context.

The Ω^- particles are identified through their two-step decay:

$$\Omega^- \longrightarrow K^- \Lambda (\Lambda \longrightarrow p \pi^-).$$

The first stage of the selection procedure is analogous to that used previously [9] in the study of the topologically similar decays

$$\Xi^- \longrightarrow \pi^- \Lambda (\Lambda \longrightarrow p \pi^-).$$

In the following we shall refer to Ξ^- 's and Ω^- 's as *cascades*.

We first select the Λ candidates as described in [10], retaining only those candidates whose invariant mass falls in a 60 MeV wide bin centred at the Λ mass. We then look for the points of closest approach between the line of flight of a Λ ($\bar{\Lambda}$) and all negatively (positively) charged tracks detected in the same event. Only cascade candidates where the distance of closest approach is smaller than 2.0 cm are retained. We also require that the reconstructed cascade traces back to the primary vertex, by demanding that the cascade impact parameter, projected on the bending plane, be less than 1.5 cm.

Since the Ω^- signal is rare (some three orders of magnitude smaller than the Λ signal), it is vital that all known sources of background be kept under control and carefully eliminated or subtracted. In our experiment, there are three main sources of background to the Ω^- signal:

- uncorrelated Λ - negative track combinations, mainly coming from the target region,
- secondary interactions in air,
- reflection of the Ξ^- peak.

We shall discuss them consecutively.

In our setup, the decay region for Ξ^- 's, Ω^- 's and Λ 's is located before the tracking chambers. The bend plane projections of the backwards extrapolated Λ and negative track trajectories generally cross twice. Borrowing a terminology in use for V^0 topologies, we call the upstream crossing *cowboy*, and the downstream crossing *sailor*. It can be shown that in a constant magnetic field, the trajectory of the parent cascade particle in the bending plane projection goes through both these crossings. In other words, there is no way, from kinematics, of telling which of the two was the physical decay point of the cascade by looking at the bending projection only, and any decision on this matter relies only on information from the non-bending projection. It can also be shown that in the ultrarelativistic regime, for a given type of cascade, the distance between the cowboy and sailor crossings is independent of the momentum of the parent particle, and is only a function of the CM system decay angles. These distances are distributed between zero and a maximum value d_{MAX} ; for $B = 1.8$ T, $d_{\text{MAX}} = 60$ cm for $\Xi^- \rightarrow \pi^- \Lambda$ decays and 115 cm for $\Omega^- \rightarrow K^- \Lambda$ decays. A similar cowboy-sailor ambiguity is also present for $\Lambda \rightarrow p\pi^-$ decays. There the maximum distance for our field value is 40 cm.

When looking for Ξ^- 's [9], we search for the minimum distance in space between the Λ and the negative track, and in general find two relative minima: one in the cowboy crossing region, and one in the sailor crossing region. We choose the absolute minimum (if the distance is smaller than 2 cm) to define the Ξ^- vertex position; we then require that it lies inside a fiducial region far away from the target (100 cm at least), in order to get rid of background from the primary vertex region. This approach cannot be transferred as it is to the Ω^- study: going from Ξ 's to Ω 's the distances between the cowboy and sailor crossings are on average doubled, so that now a cowboy topology coming from the target region can have the sailor crossing inside the fiducial region. Any kind of vertex choice, be it via a distance minimization or a more complex fit, relies on extrapolation in the non-bending projection from the chambers back towards the target and, as extrapolation errors increase with the distance, it could happen that the sailor vertex is wrongly chosen with the result that background events would be selected. This is the first source of background quoted above, which we remove by requiring that both crossings lay inside a fiducial region starting at 100 cm downstream of the target and ending at the position of the first wire chamber, 230 cm from the target. Then, since the values of cascade parameters such as momentum, mass, impact parameter, CM system decay angle ϑ^* , are the same when calculated at any of the two crossings, we do not attempt to select which vertex was the physical one, while still evaluating cascade parameters at the best crossing. Such an approach is then robust against extrapolation errors, and its acceptance does not depend on the details of the vertex choice, which gives a better control over acceptance correction systematics. In addition, we require that the sailor crossing of the Λ be after the cowboy crossing of the cascade, necessary condition for the Λ having been produced by the cascade decay.

The second potential source of background to be dealt with is secondary interactions in air. From a secondary interaction one may get several tracks, two of which may be combined to simulate a Λ , while a third one can be combined with the Λ to simulate a cascade topology. In this case, the “ Λ ” and cascade vertices are physically in the same place, so they tend to be reconstructed close to one another. In figure 1a, we plot the distribution of the distances between the best (absolute minimum distance) of the two V^0 vertices and the best of the two cascade vertices for a sample selected by all

the final cuts except the $q_T(\Lambda)$ cut described below. A clear accumulation around zero, as expected for secondary interactions, is seen. We studied these candidates further, by selecting a *short distance* sample for which this (V^0 - cascade) distance is below 20 cm, and found other anomalies. We indicate by $q_T(\Lambda)$ the transverse momentum of the “ Λ ” daughters with respect to the “ Λ ” line of flight. The $q_T(\Lambda)$ distribution for this short distance sample is plotted in figure 1b, while in figures 1c and 1d we plot the corresponding distributions respectively for a *long distance* sample, complementary to the short distance one, and for a typical Λ sample, as a reference. While the long distance candidates display the expected Jacobian peak at $q_T(\Lambda) \sim 100$ MeV/ c , the short distance ones are concentrated at lower $q_T(\Lambda)$ values. Also, the short distance candidates have lower values of the kaon momentum than the long distance ones (this type of background in fact accumulates at threshold, below the Ω^- mass). These characteristics (short (V^0 - cascade) distance, low $q_T(\Lambda)$, low kaon momentum) should be completely uncorrelated for real cascades, while here they are simultaneously found in the same events. We therefore conclude that the short distance sample events are due to secondary interactions, and remove this background by requiring that $q_T(\Lambda) > 80$ MeV/ c .

The last known source of background is Ξ^- reflection: a known problem [12] in the identification of Ω^- ’s through their decay into a Λ and a K^- consists in distinguishing them from the topologically similar decays of Ξ^- ’s into a Λ and a π^- . In the absence of π/K identification, this is only possible in the decay phase space region where the two disintegrations are kinematically unambiguous. Taking into account our experimental resolution such a region corresponds to $\cos(\vartheta^*) < 0.33$, where ϑ^* is the angle between the momentum of the Λ and the line of flight of its parent, in the parent’s CM system, under the hypothesis that the negative track is a kaon. This is illustrated in fig.2, where we plot the (ΛK^-) and $(\Lambda \pi^-)$ masses for samples obtained applying all the final cuts except for the $\cos(\vartheta^*) < 0.33$ cut (2a,2b), and with this cut also applied (2c,2d). A peak at the Ω^- mass is visible in the (ΛK^-) spectrum in fig 2a, over a broad background, but a clear Ξ^- peak is present in the $(\Lambda \pi^-)$ spectrum for the same sample in fig 2b. When the cut is applied, the Ξ^- peak disappears (fig 2d), while we still get an Ω^- peak (fig 2c). Of the four entries still remaining near the Ξ^- mass region (shaded in fig 2d), only one goes in the bin centred at the Ω^- mass in fig 2c.

The (ΛK^-) spectrum with all the final cuts is shown in figure 3 (solid line). The second bin is centered at the Ω^- mass, and is 50 MeV wide. It contains 14 entries, including both particles and antiparticles.

We have evaluated the residual combinatorial background under our Ω^- signal by merging every Λ from our sample with the non- Λ tracks of the previous Λ event. Every Λ was taken once, so we have a sample which is automatically normalized to our full statistics. We have checked the reliability of this simulation by verifying that it reproduces well both the shape and the normalization of the background to the Ξ^- peak in the $(\Lambda \pi^-)$ spectrum for various sets of experimental cuts. The background to the (ΛK^-) spectrum with final cuts is shown in figure 3 (dashed line). We estimate a contamination of 3 entries in the 50 MeV Ω^- bin, including both charges. After subtraction we are left with 7.0 ± 3.6 Ω^- ’s and 4.0 ± 2.0 $\overline{\Omega^-}$ ’s, which gives the ratio $\overline{\Omega^-}/\Omega^- = 0.57 \pm 0.41$ in the phase space region $2.5 < y_{\text{LAB}} < 3.0$ and $p_T > 1.6$ GeV/ c . This ratio is uncorrected for possible differences in acceptance and efficiency for Ω^- ’s and $\overline{\Omega^-}$ ’s. Geometrical effects are negligible, since our apparatus is left-right symmetric in the bend view, and most of the residual asymmetries in detector alignment and efficiency cancel out, as we have approximately the same statistics for the two opposite magnetic field polarities. Any further asymmetries in the reconstruction efficiencies have still to be evaluated; we do not expect them to be large.

In conclusion: we have detected an $\Omega^- + \overline{\Omega^-}$ signal in sulphur-tungsten central interactions at 200 A GeV/ c , and we have measured the ratio $\overline{\Omega^-}/\Omega^- = 0.57 \pm 0.41$ in the phase space region

$2.5 < y_{\text{LAB}} < 3.0$ and $p_{\text{T}} > 1.6 \text{ GeV}/c$.

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Figure Captions

- Fig. 1 Distribution of the distances between the best V^0 vertex and the best cascade vertex (a). $q_{\text{T}}(\Lambda)$ for the short distance sample (b), the long distance sample (c), a typical Λ sample (d). See text for cuts and definitions.
- Fig. 2 Invariant mass distributions without the $\cos(\vartheta^*)$ cut: $(\Lambda K^- + \bar{\Lambda} K^+)$ (a) and $(\Lambda \pi^- + \bar{\Lambda} \pi^+)$ (b); with the $\cos(\vartheta^*)$ cut: $(\Lambda K^- + \bar{\Lambda} K^+)$ (c) and $(\Lambda \pi^- + \bar{\Lambda} \pi^+)$ (d).
- Fig. 3 $\Lambda K^- + \bar{\Lambda} K^+$ final mass spectrum. Solid line = data, dashed line = combinatorial background.

Fig. 1

Fig. 2

Fig. 3