Particle - antiparticle asymmetries in the production of baryons in 500 GeV/c π⁻-nucleon interactions

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We present the Fermilab E791 measurement of baryon - antibaryon asymmetries in the production of Λ°, Ξ, Ω and Λc in 500 GeV/c π⁻-nucleon. Asymmetries have been measured as a function of $x_F$ and $p_T^2$ over the range $-0.12 < x_F < 0.12$ and $p_T^2 < 4 (\text{GeV/c})^2$ for hyperons and $-0.1 < x_F < 0.3$ and $p_T^2 < 8 (\text{GeV/c})^2$ for the Λc baryons. We observe clear evidence of leading particle effects and a basic asymmetry even at $x_F = 0$. These are the first high statistics measurements of the asymmetry in both the target and beam fragmentation regions in a fixed target experiment.

Particle - antiparticle asymmetry is an excess in the production rate of a particle over its antiparticle (or vice-versa). It can be quantified by means of the asymmetry parameter

$$A = \frac{N - \bar{N}}{N + \bar{N}},$$

where $N$ ($\bar{N}$) is the number of produced particles (antiparticles).

Measurements of this parameter show leading particle effects, which are manifest as an enhancement in the production rate of particles which have one or more valence quarks in common with the initial (colliding) hadrons, compared to that of their antiparticles which have fewer valence quarks in common.

Other effects, such as associated production of meson and baryons can also contribute to a non-zero value of the asymmetry parameter.

Leading particle effects in charm hadron production have been extensively studied in recent years from both the experimental [1] and theoretical point of view [2]. The same type of leading particle effects are expected to appear in strange hadron production. Although previous reports of global asymmetries in Λ°, Ξ and Ω hadroproduction already exist [3], there is a lack of a systematic study of light hadron production asymmetries.

From a theoretical point of view, models which can account for the presence of leading particle effects in charm hadron production use some kind of non-perturbative mechanism for hadronization, in addition to the perturbative production of charm quarks [3].

Given E791’s π⁻ beam incident on nucleon targets, strong differences are expected in the asymmetry in both the $x_F < 0$ and $x_F > 0$ regions. In particular, as Λ (or Λc) baryons are double leading in the $x_F < 0$ region while both Λ (Λc) and Λ (Λc) are leading in the $x_F > 0$ region, a growing asymmetry with $|x_F|$ is expected in the negative $x_F$ region and no asymmetry is expected in the positive $x_F$ region. Ξ⁻ baryons are leading in both the positive and negative $x_F$ regions, whereas Ξ⁺ are not. Thus a growing asymmetry with $|x_F|$ is expected in this case. Ω± are both non leading, so no asymmetry is expected at all.

Experiment E791 recorded data from 500 GeV/c π⁻ interactions in five thin foils (one platinum and four diamond) separated by gaps of 1.34 to 1.39 cm. Each foil was approximately 0.4% of a pion interaction length thick (0.6 mm for the platinum foil and 1.5 mm for the carbon foils). A complete description of the E791 spectrometer can be found in Ref. [4].

An important element of the experiment was its extremely fast data acquisition system [4] which, combined with a very open trigger requiring a beam particle and a minimum transverse energy deposited in the calorimeters, was used to record a data sample of $2 \times 10^{10}$ interactions.

The E791 experiment reconstructed more than $2 \times 10^5$ charm events and many millions of strange baryons.

Hyperons produced in the carbon targets and with decay point downstream the SMD planes were kept for further analysis.
Λ° were selected in the \( p\pi^- \) and c.c. decay mode. All combinations of two tracks with an \textit{a priori} Cherenkov probability of being identified as a \( p\pi^- \) combination were selected for further analysis if the tracks have a distance of closest approach less than 0.7 cm from the decay vertex. In addition, the invariant mass was required to be between 1.101 and 1.127 GeV/\( c^2 \), the ratio of the momentum of the proton to that of the pion was required to be larger than 2.5 and the reconstructed Λ° decay vertex must be downstream of the last target. The impact parameter must be less than 0.3 cm if the particle decays within the first 20 cm and 0.4 if decaying more than 20 cm downstream of the target region.

Ξ’s were selected in the \( \Lambda^0\pi^- \) and c.c. decay mode and at the same time Ω’s were selected in the \( \Lambda^0K^- \) and c.c. channel. Starting with a \( \Lambda^0 \) candidate, a third distinct track was added as a possible pion or kaon daughter. All three tracks were required to be only in the drift chamber region. Cuts for the daughter \( \Lambda^0 \) were the same as above, except for that on the impact parameter. The invariant mass for the three track combination was required to be between 1.290 and 1.350 GeV/\( c^2 \) and 1.642 and 1.702 GeV/\( c^2 \) for Ξ and Ω candidates respectively. In addition, the Ξ and Ω decay vertices were required to be upstream the \( \Lambda^0 \) decay vertex and downstream the SMD region. For Ω’s, the third track had to have a clear kaon signature in the Cherenkov counter.

From fits to a gaussian and a linear background we obtained 2,571,700 ± 3,100 \( \Lambda^0 \) and 1,669,000 ± 2,600 \( \Lambda^0 \) from approximately 6.5% of the total E791 data sample, 996,200 ± 1,900 \( \Xi^- \) and 706,600 ± 1,700 \( \Xi^+ \) and 8,750 ± 130 Ω− and 7,469±120 Ω+, these last four being from the total E791 data sample. The final data samples for hyperons are shown in Fig. 1.

For charm baryons, the five targets were used. In most cases, \( \Lambda_c \)'s decayed in air between the target foils, and before entering the silicon vertex detectors. All combinations of three tracks consistent with an \textit{a priori} Cherenkov probability of being identified as a \( pK\pi \) and c.c. combination were selected for further analysis if the distance between \( \Lambda_c \) decay vertex to the primary vertex was at least 5 standard deviations, and the invariant mass was between 2.15 and 2.45 GeV/\( c^2 \). To further enrich the sample, we required the \( \Lambda_c \) to decay at least 5 standard deviations downstream of the nearest target foil and between one and four lifetimes. The \( \Lambda_c \) momentum vector, reconstructed from its decay products, was required to pass within 3\( \sigma \) of the primary vertex. It was required that primary and secondary vertex had acceptable \( \chi^2 \) per degree of freedom. We also required that at least two of the three \( \Lambda_c \) decay tracks be inconsistent with coming from the primary vertex. The final data sample, fitted to a gaussian plus a quadratic background has 1,025 ± 45 \( \Lambda_c^+ \) and 794 ± 42 \( \Lambda_c^- \). The invariant mass plot for the \( pK\pi \) combination is shown in Fig. 1.

For each baryon - antibaryon pair, an asymmetry both as a function of \( x_F \) and \( p_T^2 \) was calculated by means of eq. 1. Values for \( N (\overline{N}) \) were obtained from fits to the corresponding effective mass plots for events selected within specific \( x_F \) and \( p_T^2 \) ranges. In all cases, well defined particle signals were evident.

Efficiencies and geometrical acceptances were estimated using a sample of Monte Carlo (MC) events produced with the PYTHIA and JETSET event generators. These events were projected through a detailed simulation of the E791 spectrometer and then reconstructed with the same algorithms used for data. In the simulation of the detector, special care was taken to represent the behaviour of tracks passing through the dead-
Figure 2. $pK^-\pi^+$ and $\bar{p}K^+\pi^-$ mass distributions showing clear $\Lambda_c^+$ and $\Lambda_c^-$ signals in each case in $x_F < 0$ and $x_F > 0$ regions. From fits with a Gaussian and a parabolic background we obtained $122 \pm 17 \Lambda_c^+$ (a) and $92 \pm 15 \Lambda_c^-$ (b) in the negative $x_F$ and $903 \pm 42 \Lambda_c^+$ (c) and $702 \pm 40 \Lambda_c^-$ in the positive $x_F$ regions.

Figure 3. $\Lambda^\circ$, $\Xi$ and $\Omega$ asymmetries as a function of $x_F$ (upper right) and $p_T^2$ (lower right). The asymmetry for $x_F$ ($p_T^2$) is integrated over all the $p_T^2$ ($x_F$) range of the data set. The left column figures show the predictions of PYTHIA/JETSET.

Asymmetries in the corresponding $x_F$ ranges integrated over our $p_T^2$ and in the corresponding $p_T^2$ range integrated over our $x_F$ range are shown in Fig. 3 and 4 for hyperons and $\Lambda_c$ baryons respectively, in comparison with predictions from the default PYTHIA/JETSET.

We have presented data on hyperon and $\Lambda_c$ production asymmetries in the central region for both $x_F > 0$ and $x_F < 0$. The range of $x_F$ covered allowed the first simultaneous study of the hyperon and $\Lambda_c$ production asymmetry in both the negative and positive $x_F$ regions in a fixed target experiment. Our results show, in all cases, a positive asymmetry after acceptance corrections over all the kinematical range studied.

Sources of systematic uncertainties were checked in each case. For hyperons we looked for effects coming from changes in the main selection criteria, minimum transverse energy in the calorimeter required in the event trigger, uncertainties in the relative efficiencies for particle and antiparticle, effects of the 2.5% $K^-$ contamination in the beam, effects of $K^0$ contamination in the $\Lambda^\circ$ sample, stability of the analysis for different regions of the fiducial volume and binning effects. For $\Lambda_c$'s we checked the effect of varying the main selection criteria, the effect of the kaon contamination in the beam, the contamination of the data sample with $D$ and $D_s$ mesons decaying in the $K\pi\pi$ and $KK\pi$ modes and the parametrization of the background shape.

Systematic uncertainties are small and negligible in comparison with statistical errors for the $\Lambda_c$ asymmetry. However they are not for the hyperons, and are included in the error bars.
Figure 4. $\Lambda^+/\Lambda^-$ asymmetry as a function of $x_F$ (upper) and $p_T^2$ (lower). Full lines are the prediction of PYTHIA/JETSET. The asymmetry for $x_F$ ($p_T^2$) is integrated over all the $p_T^2$ ($x_F$) range of the data set. The thin horizontal lines are for reference only. Experimental points are in the center of the corresponding bin.

Our results are consistent with results obtained by previous experiments [3].

Our data shows that leading particle effects play an increasingly important role as $|x_F|$ increases. The non-zero asymmetries measured in regions close to $x_F = 0$ suggest that energy thresholds for the associated production of baryons and mesons play a role in particle-antiparticle asymmetries.

On the other hand, the similarity in the $\Lambda^0$ and $\Lambda_c$ asymmetries as a function of $x_F$ (see Fig. 5) suggest that the $ud$ diquark shared between the produced $\Lambda$ baryons and Nucleons in the target should play an important role in the measured asymmetry in the $x_F < 0$ region. However, one expects the $\Lambda_c$ asymmetry to grow more slowly than the $\Lambda^0$ asymmetry due to the mass difference between the two particles.

The PYTHIA/JETSET model describes only qualitatively our results, which in turn can be better described in terms of a model including recombination of valence and sea quarks already present in the initial (colliding) hadrons and effects due to the energy thresholds for the associated production of baryons and mesons [3].

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