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 Λ_c 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 $p_T^2 < 4$ (GeV/c)^2 for hyperons and $-0.1 < x_F < 0.3$ and $p_T^2 < 8$ (GeV/c)^2 for the Λ_c 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

$$A = \frac{N - \bar{N}}{N + \bar{N}}\,, \tag{1}$$

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 nonzero 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 [2].

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 Λ_c) baryons are double leading in the $x_F < 0$ region while both Λ (Λ_c) and $\bar{\Lambda}$ ($\bar{\Lambda}_c$) 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. $\Omega^\pm$ 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 2×10^{10} interactions.

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

Hyperons produced in the carbon targets and with decay point downstream the SMD planes

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were kept for further analysis.

Λ° were selected in the $p\pi^-$ and c.c. decay mode. All combinations of two tracks with an *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 $\Lambda^\circ\pi^-$ and c.c. decay mode and at the same time Ω's were selected in the $\Lambda^\circ K^-$ and c.c. channel. Starting with a Λ° candidate, a third distinct track was added as a possible pion or kaon daugther. All three tracks were required to be only in the drift chamber region. Cuts for the daughter Λ° 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 Λ° 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 $2,571,700 \pm 3,100$ Λ° and $1,669,000 \pm 2,600$ $\bar{\Lambda}^\circ$ from approximately 6.5% of the total E791 data sample, $996,200 \pm 1,900$ Ξ^- and $706,600 \pm 1,700$ Ξ^+ and $8,750 \pm 130$ Ω^- and $7,469 \pm 120$ 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, Λ_c's decayed in air between the target foils, and before entering the silicon vertex detectors. All combinations of three tracks consistent with an *a priori* Cherenkov probability of being identified as a $pK\pi$ and c.c. combination were selected for further analysis if the distance between Λ_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 Λ_c to decay at least five standard deviations downstream of the nearest target foil and between one

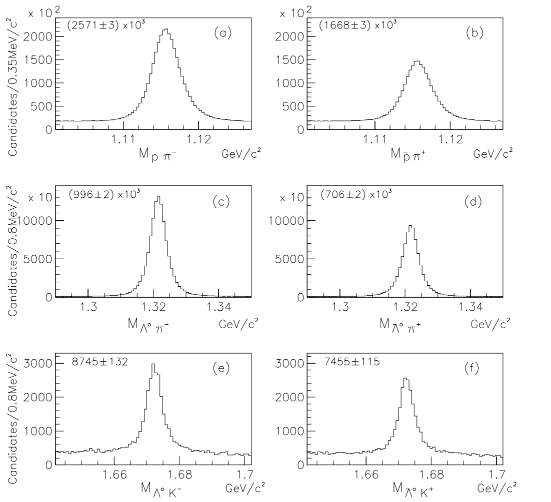

Figure 1. Λ° (upper), Ξ (middle) and Ω (lower) invariant mass plots for the final data samples. Left side figures are particles, right side are antiparticles.

and four lifetimes. The Λ_c momentum vector, reconstructed from its decay products, was required to pass within 3σ of the primary vertex. It was required that primary and secondary vertex had acceptable χ^2 per degree of freedom. We also required that at least two of the three Λ_c decay tracks be inconsistent with coming from the primary vertex. The final data sample, fitted to a gaussian plus a quadratic background has $1,025 \pm 45$ Λ_c^+ and 794 ± 42 Λ_c^-. The invariant mass plot for the $pK\pi$ combination is shown in Fig. 2.

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 [5]. 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

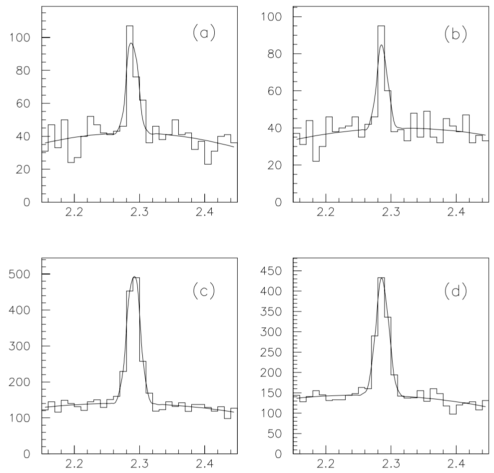

Figure 2. $pK^-\pi^+$ and $\bar{p}K^+\pi^-$ mass distributions showing clear Λ_c^+ and Λ_c^- signals in each case in $x_F < 0$ and $x_F > 0$ regions. From fits with a Gaussian and a parabolic background we obtained 122 $\pm$ 17 Λ_c^+ (a) and 92 $\pm$ 15 Λ_c^- (b) in the negative x_F and 903 $\pm$42 Λ_c^+ (c) and 702 $\pm$40 (d) Λ_c^- in the positive x_F regions.

the behaviour of tracks passing through the deadened region of the drift chambers near the beam. The behavior of the apparatus and details of the reconstruction code changed during the data taking and long data processing periods, respectively. In order to account for these effects, we generated the final MC sample into subsets mirroring these behaviors and fractional contributions to the final data set. Good agreement between MC and data samples in a variety of kinematic variables and resolutions was achieved. We generated 5 million of Λ°, 16.4 million of Ξ, 4.8 million of Ω, and 7 million of Λ_c MC events.

Sources of systematic uncertainties were checked in each case. For hyperons we looked for effects coming from changes in the main selection criteria, minimun 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° contamination in the Λ° sample, stability of the analysis for different regions of the fidutial volume and binning effects. For Λ_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 Λ_c asymmetry. However they are not for the hyperons, and are included in the error bars.

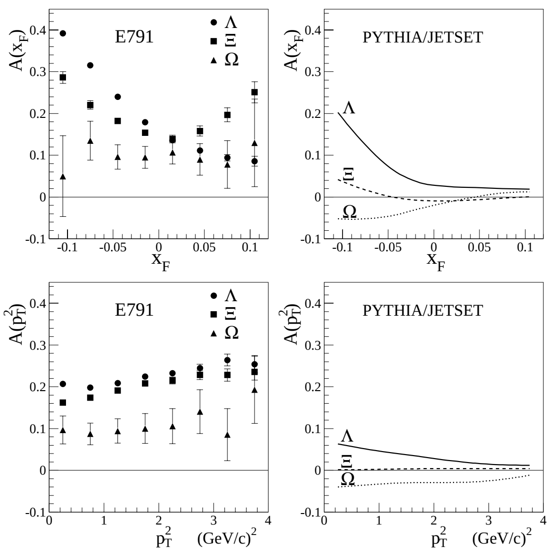

Figure 3. Λ°, Ξ and Ω asymmetries as a function of x_F (upper left) and p_T^2 (lower left). The asymmetry for x_F (p_T^2) is integrated over all the p_T^2 (x_F) range of the data set. The right column figures show the predictions of PYTHIA/JETSET.

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 Λ_c baryons respectively, in comparison with predictions from the default PYTHIA/JETSET.

We have presented data on hyperon and Λ_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 Λ_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.

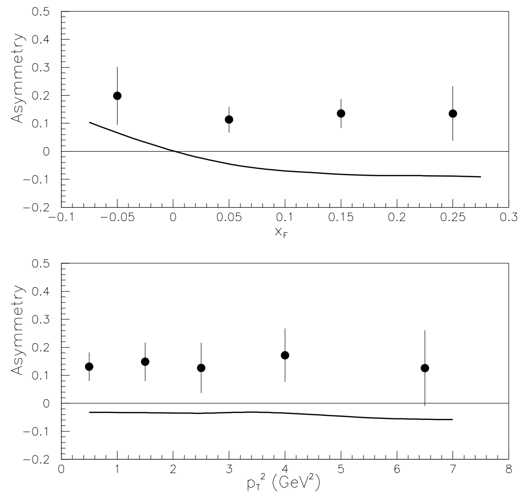

Figure 4. Λ_c^+/Λ_c^- asymmetry as a function of x_F (upper) and p_T^2 (lower). Full lines are the prediction of PYTHIA/JETSET. The asymmetry for x_F (p_T^2) is integrated over all the p_T^2 (x_F) range of the data set. The thin horizontal lines are for reference only. Experimental points are in the center of the corresponding bin.

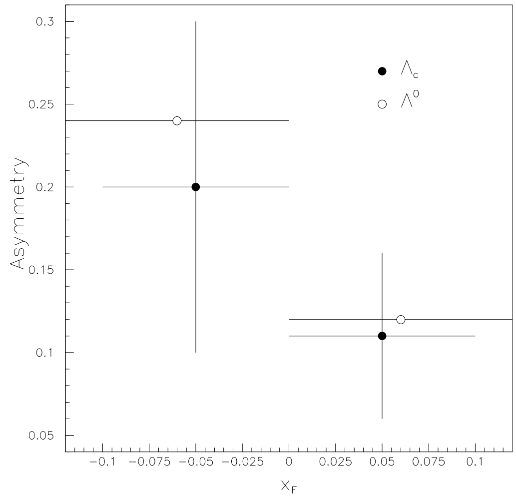

Figure 5. Comparison between the Λ° and Λ_c asymmetries as a function of x_F. The horizontal error bars indicate the size of the bin in each case.

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 Λ° and Λ_c asymmetries as a function of x_F (see Fig. 5) suggest that the ud diquark shared between the produced Λ 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 Λ_c asymmetry to grow more slowly than the Λ° 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 [6].

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