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Atomic mass dependence of Ξ^- and $\overline{\Xi}^+$ production in central 250 GeV π^--nucleon interactions

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Abstract

We present the first measurement of the atomic mass dependence of central Ξ^- and $\overline{\Xi}^+$ production. It is measured using a sample of 22,459 Ξ^-'s and $\overline{\Xi}^+$'s

produced in collisions between a 250 GeV π^- beam and targets of beryllium, aluminum, copper, and tungsten. The relative cross sections are fit to the two parameter function $\sigma_0 A^\alpha$, where A is the atomic mass. We measure $\alpha = 0.924 \pm 0.020 \pm 0.025$, for Feynman-$x$ in the range $-0.09 < x_F < 0.15$.
13.85.Ni, 12.38.Qk, 25.80.Ls

The atomic mass dependence of strong interaction cross sections with nuclear targets is sensitive to the behavior of hadrons and quarks inside nuclear matter. In addition, knowledge of this dependence is needed to compare cross section results from experiments using different target materials. Many atomic mass dependence measurements have been made [1]. Nevertheless, little exists in the literature for central hyperon production. We report here, the first measurement of the atomic mass dependence of central Ξ^- and $\overline{\Xi}^+$ production.

The atomic mass dependence of cross sections is frequently parameterized as

$$\sigma(A) = \sigma_0 A^{\alpha}, \tag{1}$$

where A is the atomic mass of the target. By using four different target materials, we are able to check the applicability of this parameterization, as well as making a measurement of α.

A model of the nucleus as a totally absorbing sphere gives a value for α of 0.67. For absorption cross sections, α is a little higher. For example, Carroll *et al.* [2] measured $\alpha = 0.755 \pm 0.010$ for a 280 GeV π^- beam. If a cross section were simply proportional to the number of nucleons in the nucleus, α would be 1.00. Earlier, we reported a measured value for α of $1.00 \pm 0.05 \pm 0.02$ for D meson production [3].

The apparatus in Fermilab experiment E769 has been previously described (see [4] and references therein). The targets were 26 foils of Be, Al, Cu, and W with a total nuclear interaction length of 2%. The foils were simultaneously exposed to the 250 GeV beam to minimize errors associated with flux measurement. A differential Čerenkov counter was used to measure the beam content and reduce contamination from kaons. The final sample consisted of 95% π^- with a contamination of 3% K^- and 2% $\overline{p}$.

The elements of the spectrometer relevant to this analysis are 11 silicon microstrip planes (1–30 cm downstream of the targets), 35 drift chamber planes (150–1750 cm), 2 multiwire proportional chambers (130 cm, 180 cm), and 2 magnets (290 cm, 620 cm) for momentum measurement. The electromagnetic and hadronic calorimeters were used only for on-line event selection. The two threshold Čerenkov counters downstream of the target were not used in this analysis.

Tracks of charged particles were reconstructed using hits in the detector planes. The Ξ^-'s were reconstructed using only the three final tracks produced in the decays $\Xi^- \to \Lambda + \pi^-$ and $\Lambda \to \pi^- + p$ (charge conjugates are implied in this paragraph and the following paragraph). The analysis focuses on events where both decays occurred between the silicon microstrip planes and the drift chamber planes. The tracks used to reconstruct Ξ^-'s were required to have hits only in the drift chambers and proportional chambers, no hits being allowed in the silicon microstrip detectors.

We applied further criteria to select Ξ^-'s from the data. The reconstructed Λ mass was required to be within 5.25 MeV of the known mass. The shortest distance between the two tracks used to reconstruct the neutral Λ was required to be less than 0.7 cm. The shortest distance between the Λ track and the other charged pion track was required to be less than 0.66 cm. The angle between the Ξ^- trajectory and the direction from the primary vertex to the Ξ^- decay vertex was required to be less than 0.012 radians. There were requirements on the geometric locations of the three vertices and on the charges of the three decay tracks. These were the most significant selection criteria.

Figure 1 shows the invariant mass distribution for candidate Ξ^-'s and $\overline{\Xi}^+$'s after the selection criteria were applied. The figure shows a strong signal over a linear background. The signal was determined using sideband subtraction, not by fitting a function to the mass distribution. This eliminates errors associated with the determination of the shape of the signal peak.

The combined Ξ^- and $\overline{\Xi}^+$ data signals, before acceptance corrections and weighting are applied, are as follows: 1980 ± 55 from a minimum bias trigger (no requirement on transverse energy in the calorimeters), and 20479 ± 187 from a trigger that required greater than roughly 5.5 GeV of transverse energy in the calorimeters. The data acquisition rates for these triggers were controlled using prescalers which were set to record a specific fraction of events that passed trigger requirements. The signals from the two triggers are combined using weights based on the known prescaler settings. Typically, the minimum bias events with less than

5.5 GeV of tranverse energy have weights roughly 20 times larger than the events from the transverse energy trigger. This causes the statistical error on α to be dominated by the statistical errors on the events from the minimum bias trigger.

A full detector simulation was used to calculate the acceptances for each material in narrow bins of x_F (width 0.015). The acceptance calculation was repeated for each data set listed in Table I. Acceptances ranged from 3% to 12%. The simulation modeled the geometry of the detector, the primary interaction, secondary interactions, pair production, multiple scattering, detector plane efficiencies, and all analysis cuts. A total of 1.8 million simulated events were generated for the acceptance calculation. The statistical errors on the acceptances were much smaller than the statistical errors from the data.

The dominant systematic error is due to the uncertainty in simulating the average number of charged particles per event (the multiplicity). The average multiplicity increases with the atomic mass of the target. Since the targets were arranged along the beam direction in order of decreasing atomic mass, events produced in the higher mass targets also suffered more pair production and secondary interactions than those produced in low mass targets. The overall effect is to reduce the acceptance for the higher mass targets, because the track reconstruction efficiency is lower in high multiplicity events. This systematic error was studied by varying the multiplicity of generated events in the simulation and by making comparisons between the data and the simulation. The systematic error on α related to multiplicity was estimated to be ± 0.023. The systematic error was somewhat higher in events where the Ξ^-'s and $\overline{\Xi}^+$'s had low transverse momenta (p_T), because the track densities were higher nearer the beam.

We studied several other sources of systematic error. Systematic errors in α associated with measurement of the thickness of the target foils, and errors associated with the location of the reconstructed primary vertex were each estimated to be roughly ± 0.007. Other systematic errors were estimated to be even smaller. These include errors related to inelastic collisions in the target that attenuate the beam flux, simulated Ξ^- and $\overline{\Xi}^+$ momentum distributions, detector geometry, signal determination, beam contamination, and trigger biases.

The values of α were determined by fitting the two parameter function $\sigma_0 A^\alpha$ to four data points: the relative Be, Al, Cu, and W cross sections. The fit parameter σ_0 simply normalizes the function. Figure 2 shows one of the fits. The χ^2 of this fit is 1.35 with two degrees of freedom. The function fits our data well.

Table I shows measured values of α for several data sets. The largest data set covers the region in x_F where the acceptance is large enough to yield enough statistics for a meaningful result. This large data set is subdivided in several different ways. When calculated separately for $\overline{\Xi}^+$ and Ξ^-, α is the same within errors. As a function of both p_T and x_F, the dependence of α is consistent with being flat within errors, but there is a rise near $x_F = 0.00$ and in the highest bin of p_T. Note that the systematic errors are strongly correlated in different subsets of data. In evaluating trends as a function of x_F or p_T, the statistical errors are more important than the systematic errors.

It is useful to compare our results to other experimental measurements. In [5,6], the atomic mass dependence for production of $\pi^\pm$, $K^\pm$, p and $\overline{p}$ was reported. That experiment used a proton beam to study central production as a function of p_T and beam energy. For example, at $p_T = 0.77$ GeV with a 400 GeV beam, α was measured to be 0.91 ± 0.01 for production of π^- and 0.98 ± 0.02 for production of both K^- and p. Our result for the atomic mass dependence of central Ξ^- and $\overline{\Xi}^+$ production is similar in that α is also a little less than 1.00. In Ref. [7], the Ξ^0 atomic mass dependence was reported for $0.2 < x_F < 0.8$ using a 400 GeV proton beam. The Ξ^0 is the particle most similar to the Ξ^-. Figures 31 and 33 of Ref. [7] show α as a function of p_T and x_F. These figures show the long established trends of α increasing as x_F decreases towards 0.0 and α increasing as p_T increases. The x_F figure shows α increasing from less than 0.5 towards a value a little less than 1.00 as x_F decreases from 0.8 to 0.0 (no data for $x_F < 0.2$ in [7]). This is consistent with our measured value for α.

In summary, we present the first measurement of the atomic mass dependence of the cross section for central Ξ^- and $\overline{\Xi}^+$ production. We measure $\alpha = 0.924 \pm 0.020 \pm 0.025$, having found that A^α is a good parameterization of the atomic mass dependence of the production cross section. Our data are consistent with the value of α approaching 1.0 as x_F approaches 0.0.

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FIGURES

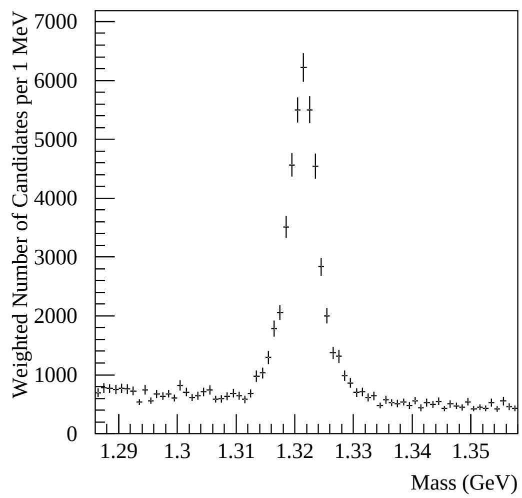

FIG. 1. Invariant mass distribution for Ξ^- and $\overline{\Xi}^+$ candidates. Mass is calculated using the known Λ mass, the known π^- mass, and the measured momenta of the three tracks (assumed to be $p\pi^-\pi^-$ or $\overline{p}\pi^+\pi^+$). Only candidates that pass the analysis cuts are included. Only statistical errors are shown. Events are weighted based on trigger prescalers. The average weight is 1.56.

FIGURES

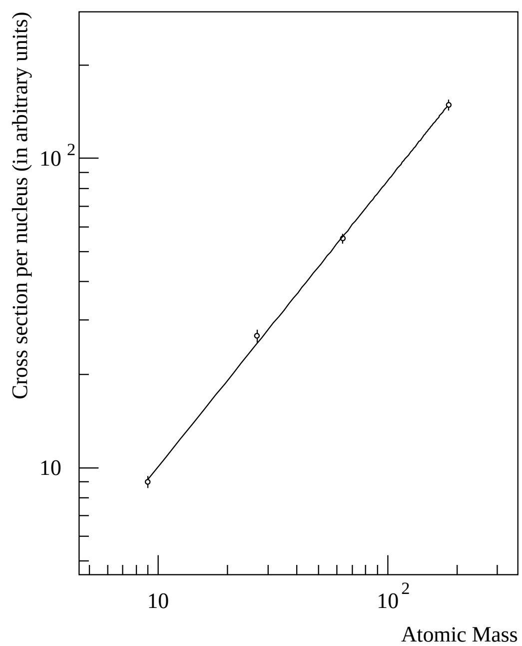

FIG. 2. Relative cross sections for $\overline{\Xi}^+$ and Ξ^- production (x_F between -0.09 and 0.15, summed over p_T) as a function of the atomic mass of the target. The solid curve shows the fit of the function $\sigma = \sigma_0 A^\alpha$, where σ_0 and α are the fit parameters. Only statistical errors are shown and used in the fit.

TABLES

TABLE I. α with statistical then systematic errors. The overall data set contains $\overline{\Xi}^{+}$'s and Ξ^{-}'s with x_F between -0.09 and 0.15, summed over p_T. The other lines show results from subsets of the overall data set with the additional selection specified in the first column.

Data Set	α in $\sigma = \sigma_0 A^{\alpha}$
Overall	$0.924 \pm 0.020 \pm 0.025$
$\overline{\Xi}^{+}$ only	$0.905 \pm 0.028 \pm 0.025$
Ξ^{-} only	$0.939 \pm 0.026 \pm 0.025$
p_T 0.0 to 0.5 GeV	$0.906 \pm 0.041 \pm 0.035$
p_T 0.5 to 1.0 GeV	$0.913 \pm 0.028 \pm 0.022$
p_T 1.0 to 1.5 GeV	$0.988 \pm 0.041 \pm 0.020$
x_F -0.09 to -0.03	$0.881 \pm 0.042 \pm 0.025$
x_F -0.03 to 0.03	$0.981 \pm 0.029 \pm 0.025$
x_F 0.03 to 0.09	$0.910 \pm 0.034 \pm 0.025$
x_F 0.09 to 0.15	$0.918 \pm 0.056 \pm 0.025$