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HYPERON PRODUCTION IN PROTON–PROTON INTERACTIONS

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A description of LPM, a phenomenological model for hyperon production, is presented. The model was developed for Λ production in 28 GeV/c proton-proton interactions using fully reconstructed events. LPM has been successfully applied to Ξ^- production in the 28 GeV/c data, with the observation that Ξ^- hyperons are not produced as leading particles in proton-proton interactions. Comparisons of the model to data for Ξ^- production in 800 GeV/c proton-proton interactions are presented.

1. Introduction

Hadronic production mechanisms are still not understood; as yet there is no fundamental theory or computer simulation that can provide an accurate prediction for the distribution of particles produced in hadronic interactions. Until there is a better understanding of the underlying production mechanisms, a phenomenological description of hadronic interactions that accurately characterizes features of the data is crucial.

We have developed a surprisingly simple phenomenological model for Λ hyperon production in proton-proton interactions using data recorded at 28 GeV/c ($\sqrt{s}$ = 7.3 GeV). The model has been successfully applied to Ξ^- production in the 28 GeV/c data, with only minor modifications required to fit the data. The model has also been tested—with encouraging results—at higher energy by comparisons to Ξ^- data in 800 GeV/c ($\sqrt{s}$ = 39 GeV) proton-proton interactions.

In this paper we present a brief description of LPM, our Λ production model (a detailed description of LPM, and numerous comparisons to data are presented elsewhere[1]). The model was developed for reactions of the type $p\,p \to p\,\Lambda\,K^+\,(\pi^+\,\pi^-)^n$, with n = 1, 2, 3, 4, 5, using fully reconstructed events (events in which *all* particles were measured and identified). These events belong to a large—2 million event—sample of fully reconstructed events recorded by experiment E766 at Brookhaven National Laboratory (BNL). The same data sample has been used to study Ξ^- production in $p\,p \to p\,\Xi^-\,K^+\,K^+\,(\pi^+\,\pi^-)^n$ reactions, with n = 0, 1, 2, 3, 4. We describe an important difference between Λ and Ξ^- production, and present preliminary results on a comparison of our model to 800 GeV/c Ξ^- data recorded by E690 at Fermilab (FNAL).

2. Features of the Data and a Description of the Model

Studies of the BNL E766 data reveal striking similarities for events with comparable particle multiplicities—independent of the types of particles produced. The most striking feature of the data involves the variation of event structure with the number of final state particles. Low multiplicity final states dominate the total cross section and overwhelmingly display an isolated proton, or less often a $\Delta(1232)^{++}$ resonance, recoiling against a relatively low mass system. With increasing multiplicity, production cross sections fall rapidly, and the event structure is such that the proton and all other final state particles are produced centrally. These features are shared by different types of reactions at $\sqrt{s}$ = 7.3 GeV, suggesting that they are general features of proton-proton interactions at this energy.

Our phenomenological model (LPM) was initially developed for Λ production, and has been applied to Ξ^- production (described in the next section). We model Λ production in $p\,p \to p\,\Lambda\,K^+\,(\pi^+\,\pi^-)^n$ reactions using two components, Model A and Model B, to simulate the two types

of event structure that we observe for low and high multiplicity final states, respectively. In both cases, reactions are modeled using a two-step process: $p\,p \rightarrow p\,X$ and $X \rightarrow \Lambda\,K^+\,(\pi^+\,\pi^-)^n$. The two-body $p\,X$ system is parameterized by the square of the proton's momentum transverse to the incident beam direction (p_t^2), and by the square of the invariant mass of system X (M_X^2). The degree of separation between the proton and all other final state particles is reflected in the M_X^2 distribution. A well separated proton implies small M_X^2; no separation is typified by large M_X^2.

Model A was designed to fit the low multiplicity Λ data, and its M_X^2 distributions peak at relatively low values. Model B was designed to fit Λ final states with the highest observed multiplicities. Its M_X^2 distributions extend to the kinematic limit. For both components of LPM, we model the breakup of the X system using p_t-limited phase space modified only by a "leading particle" function, which reproduces the observed tendency of Λ hyperons to follow the direction of the initial beam or target proton that broke up to produce the Λ. Low multiplicity reactions are simulated using only Model A, while high multiplicity reactions are reproduced using only Model B. Moderate multiplicity reactions require a combination of the two components.

This simple model fits the data extremely well. Since our events are fully reconstructed, we can compare any imaginable type of single- or multi-particle data distribution to the LPM model. With only a few parameters, LPM reproduces momentum distributions for individual particles in both low and high multiplicity final states, as well as the nonresonant background in multi-particle invariant mass distributions (LPM does not simulate hadronic resonances).

3. Ξ^- Production in 28 GeV/c Proton-Proton Interactions

We have applied LPM to Ξ^- production in five $p\,p \rightarrow p\,\Xi^-\,K^+\,K^+\,(\pi^+\,\pi^-)^n$ reactions, where $n = 0, 1, 2, 3, 4$. Only minor modifications were required to fit the data. The only significant change was the removal of the *leading particle function*, which models the leading particle effect observed for the Λ data.

We conclude that Ξ^- hyperons are not produced as leading particles in 28 GeV/c proton-proton interactions, because our model for Ξ^- production does not require a leading particle function to fit the data. Numerous comparisons between the model and the data are presented elsewhere[1]. Here we present one such comparison in Figure 1, which shows the Ξ^- center-of-mass longitudinal momentum (p_z) with respect to the beam direction for the full, kinematically allowed, momentum range. Distributions for generated Monte Carlo events are shown in the left column of histograms, and to the right are distributions for the Monte Carlo events that have passed through a software simulation of the BNL E766 detector (solid line). The data are shown as data points with error bars. All of the distributions in Figure 1 are shown for events with the final state proton in the backward center-of-mass hemisphere (proton $p_z < 0$). For lower multiplicity final states ($n = 0$ and $n = 1$), the Ξ^- tends to be found in the forward hemisphere. This tendency is a consequence of momentum conservation, not leading-particle production.

4. Preliminary Results for Ξ^- Production in 800 GeV/c Proton-Proton Interactions

An analysis of data from FNAL E690 indicates that the *same* model that successfully simulates 28 GeV/c Ξ^- reactions can also be used to simulate Ξ^- reactions at 800 GeV/c. Although studies of these reactions have not been as extensive as the analyses carried out for the BNL E766 data, our preliminary results for 800 GeV/c proton-proton interactions are very encouraging.

FNAL E690[2] employed the same multiparticle spectrometer, with minor modifications, used for BNL E766[3]. In addition to the main spectrometer, E690 also used high-rate drift chambers[4]

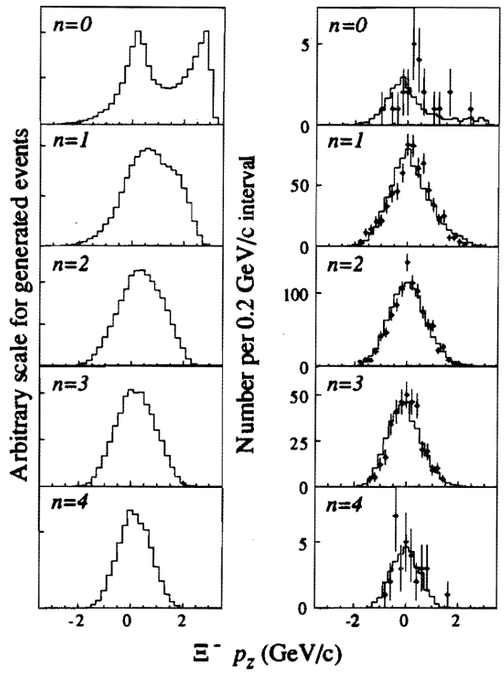

Fig. 1: $\Xi^- p_z$ distributions in the center-of-mass frame for 28 GeV/c $p\,p \rightarrow p\,\Xi^- K^+ K^+ (\pi^+ \pi^-)^n$ reactions, with n = 0, 1, 2, 3, 4. On the left are the distributions for generated events, and on the right are comparisons between these events (after detector simulation) and E766 data.

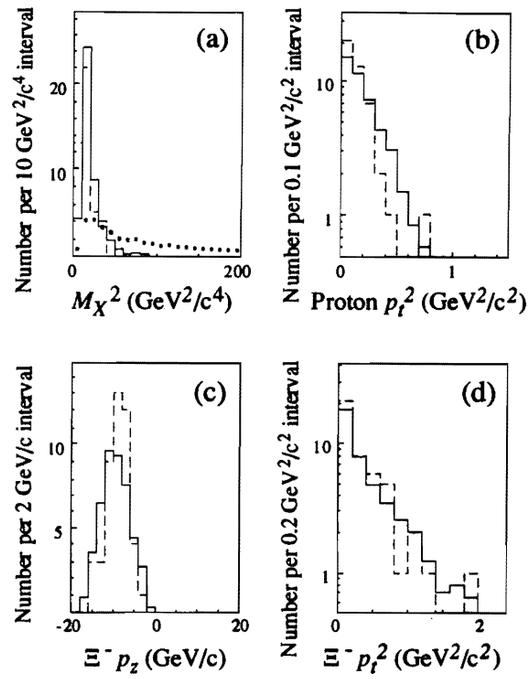

Fig. 2: (a) M_X^2, (b) proton p_t^2, (c) $\Xi^- p_z$, and (d) $\Xi^- p_t^2$ for E690 data (dashed lines) compared to events generated with the Ξ^- model (solid lines) for 800 GeV/c proton-proton interactions. Data points in (a) show the inclusive M_X^2 distribution (rescaled for comparison).

in a beam spectrometer to reconstruct incoming and outgoing beam protons. The experiment triggered on a forward proton in the beam spectrometer. The recoil system, produced opposite the forward-going proton, was measured by the multiparticle spectrometer.

For our study of Ξ^- production, we used a sample of 1.5×10^8 events, representing 3% of the data recorded by E690. This data was analyzed by reconstructing particle trajectories for momentum measurements, and by using trajectory crossings to find and fit interaction vertices and decay vertices. All Ξ^- hyperons were identified by finding a Ξ^- decaying to $\Lambda\pi^-$, followed by a decay of the Λ to $p\pi^-$. After completing the track and vertex reconstruction for the data, we extracted a sample of 6864 inclusive Ξ^- events. With additional cuts requiring momentum conservation and charge conservation, we extracted 19 events for the reaction $p\,p \rightarrow p\,\Xi^- K^+ K^+$ and 26 events for the same type of reaction with two additional charged particles (presumably π^+ and π^-). Due to the small number of events, we combined these two types of events for comparisons of the data to our Ξ^- production model.

Figure 2 shows several distributions for Monte Carlo events generated with our Ξ^- model (solid lines) compared to data (dashed lines). Figure 2(a) shows one of the important parameters of the model, the square of the invariant mass of the recoil system (M_X^2) produced opposite the final state proton. The peak at low M_X^2 for low multiplicity reactions is the same at 800 GeV/c as it is at 28 GeV/c. The data points in Figure 2(a) show the M_X^2 distribution for *inclusive* Ξ^- events. This distribution has been rescaled to an equal number of events for comparison to M_X^2 for the exclusive Ξ^- events, showing that the inclusive data has a broad M_X^2 distribution with a

long tail that extends to 400 GeV^2/c^4 (the full range is not shown in the figure). Figure 2(b) shows the other important parameter of the model, the p_t^2 distribution of the final state proton. Protons are generated with a $dN/dp_t^2 \sim e^{-4p_t^2}$ distribution, in agreement with the 28 GeV/c data, while the 800 GeV/c data displays a more rapidly falling proton p_t^2 distribution.

Figures 2(c) and 2(d) show the Ξ^- center-of-mass longitudinal momentum and the transverse momentum squared with respect to the incident beam direction. Despite the limited statistics, there is good agreement between the model and the data.

5. Conclusions

Studies of BNL E766 data for hyperon production in 28 GeV/c proton-proton interactions reveal that complex hadronic final states—often involving numerous particles of different types—can be characterized in a simple manner using a phenomenological model (LPM). Our model, which was developed for Λ production using fully reconstructed events, has been successfully applied to Ξ^- production in the 28 GeV/c data, requiring only minor modifications. The only significant modification was the removal of the leading particle effect, which was required to fit the Λ data but not the Ξ^- data.

Preliminary results from FNAL E690 show that the same model that simulates Ξ^- production in 28 GeV/c proton-proton interactions does a remarkable job of simulating the production of Ξ^- hyperons in low multiplicity reactions at 800 GeV/c. Only one parameter of the model, the p_t^2 distribution of the final state proton, depends on the momentum of the beam proton. Both the ease with which LPM has been applied to reactions for which it was not developed, and the similarities between different types of reactions suggest that the model has a broad range of applicability. Additional comparisons of the LPM model to data should be performed—both for data involving different types of particles and data at different energies—to study the usefulness of this model for accurate simulations of particle production, and to advance our understanding of hadronic interactions.

6. Acknowledgements

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