LA--9386-MS

DE82 019190

LAMPF II— Also a Hyperon Factory

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LAMPF II - ALSO A HYPERON FACTORY

by

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ABSTRACT

The possibility of generating large numbers of hyperons via an intense 4.5 GeV/c K^- beam at LAMPF II is explored. The advantage of using a K^- beam over that of using a π beam is examined. Hyperon fluxes and backgrounds are estimated and compared with those available from existing hyperon beams. Production mechanisms are briefly discussed.

INTRODUCTION

Hyperons are produced from beams of kaons, pions, or protons. At LAMPF II a high-intensity beam of $10^8 K^-/s$ at 4.5 GeV/c will be available. In the first section of this note, the yield of hyperons generated by such a beam is estimated. In the second section the yield of hyperons using a beam of pions is also evaluated and compared with the yield using negative kaons. In the third section hyperon beams from proton collisions are discussed, and in the fourth section these beams are compared with the hyperon yields from K^- interactions.

HYPERONS FROM K^- INTERACTIONS

For a beam line of 45-m length at LAMPF II, THE K^- flux peaks at 4.5 GeV/c (Fig. 1).¹ Near this momentum inclusive hyperon cross sections are:

REF.	HYPERON	INCLUSIVE CROSS SECTION AT 4.2 GeV/c
2	Λ/Σ^0*	4.5 ± 0.2 mb
3	Σ^+	1.2 ± 0.1 mb
4	Ξ^-	157 ± 8 μ b
5	Ω^-	0.5 ± 0.1 μ b

* $\Sigma^0 \rightarrow \Lambda\gamma$ is not distinguished from direct Λ production.

Above a few GeV/c, cross sections are roughly constant (Figs. 2-4).⁴⁻⁶ Little or no advantage exists in raising the beam momentum beyond 4.5 GeV/c to increase the hyperon yield. The exception is Ω^- production. Threshold for Ω^- production is 3.2 GeV/c, so here substantial gains can be made by increasing the momentum.

Assuming a K^- flux of 10^8 K^- /s at 4.5 GeV/c, the yield of hyperons in a one-interaction-length target is:

HYPERON:Y	YIELD/S	$\sigma(K^-P \rightarrow YX)/\sigma_{total}$
Λ/Σ^0	1.8×10^7	1.8×10^{-1}
Σ^+	4.8×10^6	4.8×10^{-2}
Ξ^-	6.3×10^5	6.3×10^{-3}
Ω^-	2.0×10^3	2.0×10^{-5}

Tabulated also is the ratio of hyperon-generated events to all events, where a total K^-P cross section of 25 mb is used.⁷

To take full advantage of these yields, detectors that can handle the high-incident kaon flux and backgrounds from unwanted interactions in the target are required. In addition, good acceptance in Feynman X of the hyperon is needed. The acceptance needed varies for each hyperon being studied.

The production of lambdas peaks at X near zero, with more lambdas being produced backward than forward in the CM frame (Fig. 5).⁸ This lack of symmetry may be understood in the multiperipheral model where baryon and meson exchange contribute unequally to Λ production:

For baryon exchange, forward production of the Λ is expected because the strange quark of the Λ follows the initial direction of the kaon, collecting two quarks from the proton to complete its formation. Just the opposite occurs in meson exchange, where the strange quark of the incoming kaon is transferred to the backward-traveling proton. For meson exchange, backward production of the Λ is expected.

Similar comments can be made about sigmas production because the strangeness content is the same as that of the lambda.

For the production of the Ξ^- or Ω^- , single meson exchange is excluded as no meson with two or more units of strangeness exists. Accordingly, only baryon exchange is possible,

and in the multiperipheral model, forward Ξ^- or Ω^- production is expected. This behavior in X is observed for Ξ^- (Fig. 6).⁴ For Ω^- , however, an appreciable fraction of the Ω^- are produced backward, indicating perhaps that multiple exchanges are also occurring (Fig. 7).⁹

For Ω^- production at 4.2 GeV/c, the Q-value is small so that 98% of the Ω^- are produced by the threshold process⁵

Thus, although only 2 in 10^5 K^- interactions result in a Ω^- , near threshold their detection is eased by the uniqueness of the final state.

HYPERONS FROM π INTERACTIONS

Between 1 and 20 GeV/c, inclusive strange-particle production by π interactions increases with pion momentum, from about 1 mb to about 4 mb (Figs. 8,9).¹⁰⁻¹² The bulk of this rise is due to $K\bar{K}$ formation, while the cross section for producing hyperons remains relatively flat. At 4.5 GeV/c the ratio

of the inclusive hyperon cross section produced by a K^- to that produced by a π^- is

$$\frac{\sigma(K^-P \rightarrow \Lambda/\Sigma^0 X)}{\sigma(\pi^-p \rightarrow \Lambda/\Sigma^0 X)} = 5.6 \quad \frac{\sigma(K^-P \rightarrow \Lambda/\Sigma^0 X)}{\sigma(\pi^+p \rightarrow \Lambda/\Sigma^0 X)} = 9$$

$$\frac{\sigma(K^-P \rightarrow \Sigma^\pm X) \times 2}{\sigma(\pi^-p \rightarrow \Sigma^\pm X)} = 8 \quad \frac{\sigma(K^-P \rightarrow \Sigma^\pm X) \times 2}{\sigma(\pi^+p \rightarrow \Sigma^\pm X)} = 4.8$$

The ratio of inclusive Ξ^- production by K^- at 14 GeV/c to inclusive Ξ^- production by π^- at 25 GeV/c is similar to the above ratios and is^{4,10}

$$\frac{\sigma(K^-P \rightarrow \Xi^- X)}{\sigma(\pi^-p \rightarrow \Xi^- X)} = 6.3$$

For π^+ interactions, the Λ are strongly produced in the backward direction, whereas the $\bar{\Lambda}$ are produced slightly forward (Fig. 10).¹¹ The data suggest that the dominant mechanism of Λ production is the fragmentation of the proton. In particular, the proton diffractively dissociates into ΛK^+ , $(\Lambda K\pi)^+$, ... combinations. The X distribution of the $\bar{\Lambda}$, on the other hand, suggests central $\bar{\Lambda}$ production via $\Lambda\bar{\Lambda}$ pairs.

Pion beams can be made many orders of magnitude more intense than kaon beams. Because the efficiency in producing hyperons by kaons is less than one order of magnitude over that in producing them by pions, the advantage in using kaons instead of pions to produce hyperons is not in absolute hyperon flux. Rather, because the total cross sections for K and for π interactions are similar to each other above a few GeV/c, the advantage is the higher rate of hyperon production to nonhyperon production. Thus a given detector, using incident K^- particles, needs to withstand a lower incident flux in order to measure the same number of hyperons.

HYPERON BEAMS FROM P INTERACTIONS

At high energy, hyperon production by protons in the forward direction is dominated by the leading-particle effect. The baryon-to-meson ratio increases with X (Figs. 11-13).¹³⁻¹⁵ Accordingly, because the useful hyperon flux relative to the unwanted flux of mesons increases at high X and because, simultaneously, the hyperon lifetime dilates, high-energy beams of hyperons have been possible to produce.

The hyperon fluxes have not been limited by the incident proton flux but, instead, by the total flux an apparatus located downstream of the beam can tolerate. The maximum flux is typically of the order of 10^6 particles/s.

Hyperon beams have been constructed at the BNL-AGS and the CERN-PS, which run using protons near 30 GeV/c, and at FNAL and the CERN-SPS, which run using protons of 400 GeV/c. Beams at the higher energy machines are several orders of magnitude more intense than are those at the lower energy:^{15-16*}

	AGS		PS		FNAL	SPS
	Charged	Neutral	Charged	Neutral	Neutral	Charged
P_p [GeV/c]	30	30	24	24	400	200
P/burst	1.5×10^{11}	10^{10}	10^{11}	10^9	10^8	4×10^{10}
P_Y [GeV/c]	21	8-16	13-20	3-15	70-350	70-140
Beam	$3.0 \times 10^4 \pi^-$				$2.0 \times 10^5 n$	$1.0 \times 10^6 \pi^-/p$
Λ		3.0×10^3		5×10^2	5×10^3	
Ξ^0		3.0×10^1			7.8×10^2	
Σ^-	2.6×10^2		5.0×10^1			4.0×10^3
Σ^+						4.6×10^1
Λ^-	6		1			4.0×10^2
Ω^-						1.0×10^{-1}

*This information was furnished by R. Foster, Brandeis University.

The large increase in flux results primarily because the minimum length of material required to shield an apparatus from secondaries generated at the production target and collimators grows logarithmically with energy, whereas the hyperon decay length grows linearly.

This method of hyperon production at LAMPF II, where the primary proton momentum is expected to be 16 GeV/c, is not competitive with that from machines of higher energy.

As was previously mentioned, the leading-particle effect plays an important role in hyperon production. Hyperon production, however, decreases rapidly with increase of strangeness content (Fig. 14).^{15,16} Typical losses are about 10 per unit change of strangeness. Furthermore, antiparticle-to-particle production increases rapidly with an increase in strangeness content (Fig. 14). These data suggest that the forward leading-particle effect diminishes as central pair production rises in importance when the strangeness content of the hyperon is increased.

COMPARISON OF K^- AND P PRODUCTION OF HYPERONS

A beam of charged hyperons has been recently brought into operation at FNAL. The projected rates as estimated by Doroba¹⁷ have been largely realized or exceeded (Fig. 15).^{*} Below is a comparison of these rates for 300-GeV/c hyperons with the above calculated for K^- interactions:

Y	LAMPF II Y per $10^6 K^-$	FNAL Y per $10^6 \pi^-$ or p
Σ^-		5×10^5
Σ^+	5×10^4	7×10^3
Ξ^-	6×10^3	9×10^3
Ω^-	2×10^1	1×10^1

^{*}This information was furnished by J. Lach, Fermi National Accelerator Laboratory.

Here the K^- under LAMPF II refers to the kaon flux that generates the hyperon, whereas the π or p under FNAL refers to the additional particles in the hyperon beam.

The hyperon yield at FNAL is limited by the π^- or p flux that the detectors downstream of the beam can tolerate, which is about 10^6 per second. Similar factors may also limit the usable hyperon yield at LAMPF II. Because FNAL has a 10-second cycling time with about a 1-second flat top, the absolute rates at FNAL should be reduced by 10 when being compared to LAMPF II rates. Assuming then the above normalization, with the total flux in the beam as the limiting factor, hyperon yields per second at LAMPF II are 7 to 70 times more intense than those at FNAL. Note that secondaries from K^- interactions in the target have not been included in estimating the total incident flux at LAMPF II.

CONCLUSIONS

The production of hyperons by an intense K^- beam at LAMPF II is competitive in number with those produced from the hyperon channel in proton-nucleon collisions at FNAL. The advantage of the leading-particle effect in producing hyperons at FNAL is matched by the advantage of the additional strangeness content of the kaon in producing hyperons by kaon interactions at LAMPF II.

At LAMPF II, impressive numbers of hyperons can be generated. For example, 2000 Ω^- per second are produced using 10^8 K^- per second incident on a one-interaction-length target. Substantial detector development, however, is needed to handle the intense kaon flux and thus to realize the full potential of hyperon yield.

The advantage of using a K^- beam rather than a π beam to produce hyperons is not in absolute rate, but rather in hyperon yield per incident beam flux. This ratio is roughly seven times larger for a K^- than for a π .

At LAMPF II, the hyperon energy is in the GeV region as compared to the 100- to 400-GeV beams available at FNAL or CERN. Accordingly, opening angles between secondaries from hyperons generated at LAMPF II are larger than those produced at the higher energy, easing the identification of many hyperon-decay modes. LAMPF II thus provides a unique facility that allows both the properties of hyperon decay to be studied and low-energy hyperon interactions to be explored.

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Fig. 1. Number of kaons at the exit of a 45-m beam line.

Fig. 2. Inclusive Λ and neutral-kaon cross sections in K^-p interactions as a function of the momentum of the incident K^- : $\bullet$ for K^- , $\times$ for Λ^- . The upper curve is the K^-p total cross section (Ref. 6).

Fig. 3. Inclusive E^- production cross section in K^-p interactions as a function of the momentum of the incident K^- (Ref. 4).

Fig. 4. Inclusive Ω^- cross section in K^-p interactions as a function of the momentum of the incident K^- (Ref. 5).

Fig. 5. Invariant Λ cross section as a function of x (Ref. 8).

Fig. 6. Invariant E^- cross sections as a function of x (Ref. 4).

Fig. 7. Ω^- longitudinal distribution dN/dx as a function of x . In (a) and (b), the shaded parts of the histogram denote ambiguous events. In Fig. 7c, the shaded parts refer to Ω^- particles from the three-body final state $\Omega^- K^+ K^0$ (Ref. 9).

Fig. 8. Strange particle cross sections as a function of pion momentum for $\pi^- p$ collisions (Ref. 10).

Fig. 10. Inclusive cross section for K_S^0 , Λ and $\bar{\Lambda}$ as a function of x (Ref. 11).

Fig. 9. Inclusive strange particle cross sections as a function of pion momentum for $\pi^+ p$ collisions (Ref. 11).

Fig. 11. Invariant cross sections for Σ^- and E^- production by protons on beryllium as a function of x . These data are from Hungerbuhler et al.¹⁴ and Badier et al.¹³ Production cross sections of other particles taken from Allaby et al. (1970 CERN Rep. 70-12) are shown for comparison.

$\square$ Σ^- CERN 24 GeV/c 10 mr,
 $\times$ Σ^- BNL 25.8 GeV/c 0 mr,
 $\bullet$ Σ^- BNL 29.4 GeV/c 0 mr,
 $\blacksquare$ E^- CERN 24 GeV/c 10 mr,
 $\blacktriangle$ E^- BNL 29.4 GeV/c 0 mr
 (Ref. 16).

Fig. 12. Inclusive particle production as a function of x at small p_T . The full lines are parametrizations of the form $(1-x)^n$ where n depends on the nature of the particle.

$\diamond$ $\sqrt{s} = 45$ GeV, $\circ$ 300 GeV/c,
 Δ 200 GeV/c, $\blacksquare$ 200-210 GeV/c,
 --- 19.2 GeV/c (Ref. 15).

Fig. 13. Inclusive hyperon production as a function of x at small p_T . The full lines are parametrizations of the form $(1-x)^n$ where n depends on the nature of the particle.

$\bullet$ $\blacksquare$ 200-210 GeV/c, $\diamond$ 29.4 GeV/c,
 Δ 25.8 GeV/c, $\circ$ 24 GeV/c
 (Ref. 15).