Heavy Hadrons

Report of the Study Group

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Abstract

Particle identification will be the most difficult aspect of of heavy hadron studies at PEP. We believe that this physics can be divided into two classes: 1) that amenable to analysis in stand-alone apparatus; and 2) that best approached in an "add on" way to more general experiments. We recommend the construction of a simple strange particle spectrometer, and conclude that improvement of time-of-flight resolution to 0.1 ns would be extremely useful. Heavy hadron production rates are estimated to range between $1980(E/15)^2$ and 8.8R events per hour for a luminosity of $1/4 \times 10^{32}/cm^2$-sec.

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I. INTRODUCTION

We have considered the study of heavy hadrons at PEP and believe that particle identification is its most difficult aspect. Table I lists the hadrons and their signatures.

Table I

Particle	Handles: Slow($\sim$0.5 GeV/c)	Handles: Fast ($\sim$ 5 GeV/c)	Stand-Alone
K^+	TOF, $\vec{p}$		
K^-	" "		
K_s^o	Decay	Decay, separate, Vertex	Yes
K_L^o	-		
η	-		
ρ	-		
ω	-		
η'	-		
p	TOF, $\vec{p}$	TOF, $\vec{p}$, β(Cer.)	
$\bar{p}$	" ", annih.	TOF, $\vec{p}$, annih,β(Cer.)	
n	TOF		
$\bar{n}$	TOF, annih.	TOF, annih.	
Λ	Decay	Decay, separate vertex	Yes
$\bar{\Lambda}$	Decay	" " "	Yes
Σ	Decay		
Δ	Decay?		

Orientation, cheap, stand-alone (e.g. Λ's) should be done as Round 0. Otherwise equipment is add-on particle i.d., too low/or high momentum detection.

We have divided heavy hadron physics into two parts: (1) that amenable to stand-alone apparatus, and (2) physics which is best approached in an "add-on" way to a more general experiment. Finally, we present some estimates of heavy hadron production rates at PEP as a guide to the feasibility of experiments.

II. THE STRANGE PARTICLE DECAY SPECTROMETER (SPDS)

By virtue of their decay properties, K^0's and Λ's have a unique identifying signature (neutral V). We recommend that a special purpose apparatus be built, exploiting this signature, and remark that the hyperon identification will be good over a broad range of momenta. (Alas, such is not true for nucleons). The SPDS is discussed in detail elsewhere,[1] including its application to weak interaction effects.

III. NUCLEON-ANTINUCLEON IDENTIFICATION

We now elaborate on the question of stable hadron identification, which we believe should be employed in an "add-on" manner in general purpose apparatus.

Events with baryon-antibaryon on pairs are characterized by the presence of a $\bar{p}$ or $\bar{n}$, n or p in the final state. The $\bar{p}$ - p - π separation in the low momentum region (below 1.5 GeV/c) can be done by time-of-flight and dE/dx measurements with appropriate overlap. The presently attainable accuracies are:

$$\Delta\tau = 0.5 \text{ ns} \quad \text{for TOF}$$

$$\Delta(dE/dx)/dE/dx = 0.2$$

Assuming a 1.5 m flight path and four dE/dx measurements, the π-p separation is illustrated in Figure 1. It is clear that if $\Delta\tau$ can be reduced the separation will improve. Since this seems intrinsic to the properties of (thin) plastic scintillator, it would be worthwhile to investigate the feasibility of other detectors. Avalanche counters[2] with parallel plate geometry might permit $\Delta\tau$ to be reduced to as little as 0.1 ns. Longer flight paths and better time resolution are essential for K-π separation.

The antinucleon's TOF ($\bar{p}$, $\bar{n}$) and dE/dx signature ($\bar{p}$) is the same as the protons, but its interaction in material far from the production vertex and the associated release of ~ 2 GeV of annihilation energy and production of several outgoing pions gives another label. The general method has been discussed by Berk[3] and has been used in an experiment at SPEAR. However, for antibaryon momenta greater than 2 GeV/c, the annihilation cross section decreases and the annihilation energy becomes a smaller fraction of the total energy available for pion production. These, unfortunately, offset the $1/\sqrt{E}$ gain in calorimetric resolution.

IV. ESTIMATES OF RATES AND EXPERIMENTAL PARAMETERS FOR PROTON PRODUCTION IN e^+e^- ANNIHILATION

A. One of the features of the SPEAR data is that, over a somewhat limited kinematic range, there appears to be a universality among pions, kaons, and protons. In particular the invariant cross sections, $E\,d\sigma/d^3p$ vs. E, for π, K and p seem to lie on top of each other for fixed s, and furthermore the curves of different s lie upon one another too. To use this hypothesis let us use the invariant cross section for all particles together and parameterize as follows; the form is assumed for all particles

$$E\,\frac{d\sigma}{d^3p} = \begin{Bmatrix} E^{-4} & E \geq 1\ \text{GeV} \\ e^{-5.12(E-1)} & E < 1\ \text{GeV} \end{Bmatrix} \times \text{constant.}$$

Taking this model and integrating we can obtain the average energy of produced hadrons, the relative fraction of π, K, p and the average fraction of the total energy carried by π, K, p. The results are shown on Table II. The average energy is seen to increase very slowly with the beam energy E_0. Likewise it appears that the particle yield fractions are already saturated at SPEAR. The SPEAR data are well reproduced by producing π, K, p with the same matrix element and letting phase space select the relative yields. Taking this model seriously means that the experiment would be dealing with fairly low momenta in the final state. This is advantageous for the problems of particle identification. The extrapolation of these SPEAR data is dangerous however.

Table II

E_o	E_{ave}	Yield			Energy		
		π/all	K/all	p/all	π/all	K/all	P/all
1.5	0.44	0.903	0.088	0.009	0.810	0.166	0.024
2.5	0.48	0.888	0.096	0.017	0.759	0.187	0.054
5.0	0.52	0.880	0.099	0.021	0.723	0.200	0.077
10.0	0.54	0.878	0.100	0.022	0.706	0.206	0.088
15.0	0.55	0.878	0.100	0.022	0.701	0.208	0.091

If one takes the model seriously then at PEP energies the total multiplicity of the final state must be dramatically larger than SPEAR just to conserve energy. Keep in mind, however, that the charged multiplicity at SPEAR is rising rather slowly. Unless a truly spectacular amount of energy disappears as neutrals then either the average energy/charged particle must rise faster than that given in Table II or the charged multiplicity must rise faster than in the SPEAR energy region.

B. Let us suppose the kind of π/K/p universality used in the first model but inject some prejudice on how charged and total multiplicities might behave. Suppose $\langle N_{ch}\rangle / \langle N_{total}\rangle \sim 0.5$, as at SPEAR, but that $\langle N_{ch}\rangle$ only rises slowly. Suppose $\langle N_{ch}\rangle \sim 8 \rightarrow \langle N_{total}\rangle \sim 16 \rightarrow E_{ave} \approx 30/16 \approx 2$ GeV. In this model the fraction of protons will be substantually larger than model A; a not unreasonable estimate is ~ 0.3, as seen at the ISR. One would want rather different apparatus for separating π-K/p for $\langle p\rangle \sim 0.5$ than for $\langle p\rangle \sim 2$ GeV/c. Thus some kind of broad band equipment is needed.

C. The model of Bjorken and Kogut[4] suggests that protons would be $\sim 10\%$ of the total yield and the $\langle p\rangle \sim 4$ GeV. This is a pair of results quite similar to model B.

D. The model of Bjorken and Farrar[5] also suggests that protons would be $\sim 10\%$ of the total yield, but makes no statement on $\langle p\rangle$

E. Absolute Rates - There are large uncertainties in estimates of the total cross section as well as the multiplicity and energy spectrum of the hadrons. The most optimistic assumption is that the total cross section remains ~20 nB, as measured at SPEAR. A much more conservative assumption is that the total cross will be a constant multiple, R, of the μ-pair cross section. Assuming a design luminosity of 10^{32} cm^{-2} sec^{-1} and a derating factor of 4 to account for equipment downtime,etc., and that the luminosity is proportional to the square of the beam energy, the optimistic estimate is ~2000 $(E_0/15\ GeV)^2$ events produced per hour; the conservative estimate is ~9 R/hour. Of these rates the relative fractions of prongs discussed in A-D contribute to the heavy hadron yield.

V. CONCLUSION AND RECOMMENDATIONS

Heavy hadron identification is difficult and with the exception of strange particles, it is especially difficult above ~2 GeV/c. We believe a SPDS could simply detect K^0's and Λ's, but feel that the physics of other hadrons may be best studied in general purpose apparatus.

References

1. D. Hitlin, J. Marx, and P. Yamin, "Strange Particle Decay Spectrometer", PEP Summery Study 1974, PEP-164.

2. This work was performed by a Russian group, but the exact reference could not be located prior to publication. - Editors note.

3. D. Berk et al., Lettere al Nuovo Cimento 9, 475 (1974).

4. J. D. Bjorken and J. Kogut, SLAC PUB 1213 (1973).

5. J. D. Bjorken and G. Farrar, SLAC PUB 1298 (1973).

Figure Caption

1. dE/dx and Time of Flight Correlation for π-p Separation at 1.5 GeV/c.

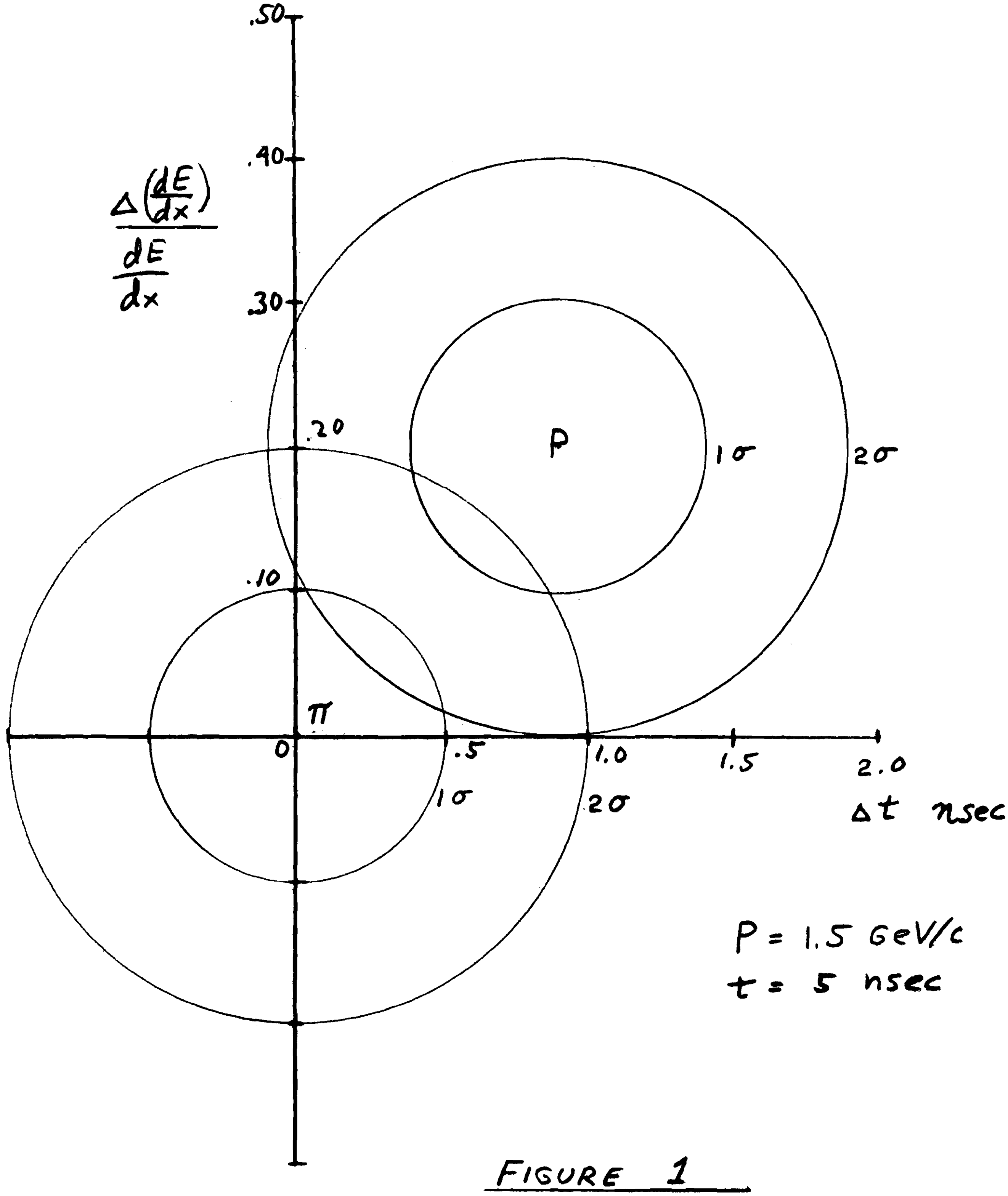
.50
.40
.30
.20
.10
$\frac{\Delta\left(\frac{dE}{dx}\right)}{\frac{dE}{dx}}$
P
1σ
2σ
π
0
.5
1.0
1.5
2.0
1σ
2σ
Δt nsec
P = 1.5 GeV/c
t = 5 nsec

FIGURE 1