**A Study of Particle Ratios and Strangeness Suppression
in $p\bar{p}$ Collisions at $\sqrt{s} = 630 \text{ GeV}$ with UA1**

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Abstract

From a sample of 2.36 million minimum bias events produced in $p\bar{p}$ collisions at $\sqrt{s} = 630 \text{ GeV}$ in the UA1 experiment and from other published data at the CERN $Spp\bar{S}$ collider we have estimated the relative production of $\pi^\pm$, π^0 , $K^\pm$, K_s^0 , Λ , $\bar{\Lambda}$, p and $\bar{p}$. We obtain a meson over baryon ratio $M/B = 6.4 \pm 1.1$. From the $K_s^0/\pi^\pm$ ratio we measure the strangeness suppression factor $\lambda = 0.29 \pm 0.02 \pm 0.01$ which, combining with other available data provides a new world average of 0.29 ± 0.015 . Both the $K_s^0/\pi^\pm$ ratio and the strangeness suppression factor λ as a function of $\sqrt{s}$ are investigated, and an extrapolation to the LHC energy is performed.

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1. Introduction

In $p\bar{p}$ collisions hadron production in the central region can be described in terms of the quark model. In the model of Anisovich *et al.* [1] the interaction region of a proton and an antiproton collision is assumed to be a chaotic blob of quarks and antiquarks. A quark leaving the zone of the interaction must pick up at least one neighboring parton from the blob in order to make a hadron. Assuming that in proton-antiproton collisions there are equal numbers of quarks and antiquarks of each flavor in the blob, there is 50% chance that the q combines with a $\bar{q}$ which is assumed to form a meson M . In the other half of the cases the qq system must combine again to form a either qqq baryon state B or if an antiquark is added a further meson state and another unconnected quark. This line of argument leads to a (M/B) ratio of 6.

Bjorken and Farrar have proposed a similar but more simplified model to study hadron production [2]. Their prediction of the meson to baryon ratio is only 2. In their model, the procedure of “joining” of a quark or an antiquark to the given quark is carried out only twice. If this procedure was continued and the antibaryon production was taken into account by counting antiparticles, the ratio would eventually approach 6 as Anisovich *et al.* pointed out. In these $SU(6)$ models the probabilities of producing u, d, s quarks are equal. However, various experiments show that the strange particle production is suppressed in some way. We can characterize the suppression of strange quark production by a parameter λ which is defined as

$$\lambda = \frac{2 \langle n_{s\bar{s}} \rangle}{\langle n_{u\bar{u}} \rangle + \langle n_{d\bar{d}} \rangle} \quad (1)$$

where $\langle n_{s\bar{s}} \rangle$, $\langle n_{u\bar{u}} \rangle$ and $\langle n_{d\bar{d}} \rangle$ are the mean numbers of s, u, d quarks and the corresponding antiquarks in the final state. $SU(6)$ symmetry implies u, d, s quarks are equivalent and $\lambda = 1$.

2. Particle Ratios

A high statistics sample of about 2.36 million minimum bias events recorded in a single collider run at $\sqrt{s} = 630 \text{ GeV}$ in 1987 in the UA1 detector are used to measure $K/h^\pm$ and $(\Lambda + \bar{\Lambda})/h^\pm$ ratios in the pseudorapidity range $|\eta| < 2.5$. Here $h^\pm$ refers to charged hadrons. Strange particles are identified by the reconstruction of secondary decay vertices well separated from the primary production vertex. K_s^0 , Λ s and $\bar{\Lambda}$ s are reconstructed as V^0 vertices and $K^\pm$ from its 3-prong decay mode : $K^\pm \rightarrow \pi^+ \pi^- \pi^\pm$. Particle identification is then made by reconstructing the mass [4]. The experimental details and the production properties are discussed in reference [3] for the charged particles and in reference [5] for the strange particles.

In these analyses the p_T spectrum for charged particles and K_s^0 is well described by the phenomenological power law function:

$$E \frac{d^3\sigma}{dp^3} = \frac{A}{(1 + p_T/p_T^0)^n} .$$

By integrating these fitted functions extrapolated to $p_t = 0$, we obtain a K_S^0 to charged hadron ratio $(\frac{2K_S^0}{h^\pm})_{UA1} = 0.077 \pm 0.004 (stat) \pm 0.003 (syst)$, where the systematic error is obtained from estimating the error due to extrapolating to $p_T = 0$. In a similar way we obtain a $K^\pm$ to charged hadron ratio measurement of $(\frac{K^\pm}{h^\pm})_{UA1} = 0.085 \pm 0.006 (stat) \pm 0.003 (syst)$. We take the $\pi^\pm$ to charged hadron ratio measurement from the UA2 experiment [6] which is $\pi^\pm/h^\pm = (0.813 \pm 0.016)$. We assume that the π^0 to charged hadron ratio is half of the $\pi^\pm/h^\pm$ ratio, that is (0.407 ± 0.008) . This is also consistent with the measurement of the $\pi^0/h^\pm$ ratio by UA2 experiment [7] of $\pi^0/h^\pm = 0.34 \pm 0.07$ but we choose to use the value derived from the $\pi^\pm$ measurement in subsequent calculations because of the smaller error. Photons from π^0 decays converting in the beam pipe and the central drift chamber will give an $e^\pm$ background to the charged hadrons. In the central region the material varies from about 2% of a radiation length at $\eta = 0$ to 20% at $\eta = 2.5$. Conservatively, we assume a uniform distribution of material corresponding to 10% of a radiation length. A small contribution from Dalitz π^0 decays is also included. We estimate this from the π^0 result by assuming that the p_T spectrum of the electrons is similar to that of the charged hadron spectrum but with $p_T(e^\pm) = 0.25p_T(h^\pm)$. Integrating the p_T spectrum from a p_T cut off value of $0.2 \text{ GeV}/c$ we estimate that $e^\pm/h^\pm = 0.010$. Not all of these will associate to the primary vertex. We therefore assign $e^\pm/h^\pm = 0.005$ with a systematic error of ± 0.005 . The direct production of $e^\pm/h^\pm$ and $\mu^\pm/h^\pm$ is assumed to be less than 10^{-4} and is therefore neglected in this study. The $(\Lambda + \bar{\Lambda})$ p_T distribution is harder than that for K^0 p_T spectrum and we fit with a simple exponential function:

$$E \frac{d^3\sigma}{dp^3} = ae^{-bp_t}.$$

Again integrating this function using the best fit parameters we obtain $(\Lambda + \bar{\Lambda})/h^\pm = (0.018 \pm 0.002)$. We are now in a position to estimate the contribution of p and $\bar{p}$ to the charged hadron fraction:

$$\frac{(p + \bar{p})}{h^\pm} = 1.0 - \frac{\pi^\pm}{h^\pm} - \frac{K^\pm}{h^\pm} - \frac{e^\pm}{h^\pm} = 0.097 \pm 0.017 \pm 0.005.$$

In order to estimate the (M/B) ratio we have to make two further assumptions. The first assumption is that $n/\bar{n}$ production equals $p/\bar{p}$ production. The second assumption is that measurement of $(\Lambda + \bar{\Lambda})$ and $(p + \bar{p})$ implicitly includes the counting of Σ , Ξ and Ω production through their decay modes. With these assumptions we calculate from the above measurements $(M/B) = 6.4 \pm 1.1$. Anisovich *et al.* [1] calculate the fraction of particle types as a function of the strangeness suppression factor λ . Fig. 1 shows these calculated fractions with respect to the charged hadrons. Also plotted are the above data points at the value of $\lambda = 0.29$ which is the value we estimate from the K/π ratio for the UA1 data as derived in the next section. The $(p + \bar{p})$ agree well with the prediction though the $(\Lambda + \bar{\Lambda})$ is about a factor two smaller than expected. Substituting the measured λ value into the model of Anisovich *et al.* [1] then we find that $(M/B)_{\lambda=0.29} = 6.57 \pm 0.02$ to be compared with the measured value of $(M/B) = 6.4 \pm 1.1$. For comparison the model gives $(M/B)_{\lambda=1} = 6$ and $(M/B)_{\lambda=0} = 6.8$.

Figure 1: Ratios to charged hadrons for different particles.

3. Strangeness Suppression Factor Measurement

Using the UA2 $\pi^\pm/h^\pm$ measurement [6], we deduce the K/π ratio $(\frac{2K_S^0}{\pi^\pm})_{UA1} = 0.094 \pm 0.005 (stat) \pm 0.004 (syst)$, where the systematic error is the combination in quadrature of the error on the $\pi^\pm/h^\pm$ ratio and the systematic error on the UA1 measurement of $(\frac{2K_S^0}{h^\pm})_{UA1}$. Comparing our K/π ratio measurement with the theoretical calculation [1], we determine the *Strangeness Suppression Factor* λ .

In terms of λ we can express the K/π ratio as:

$$\frac{2K_S^0}{\pi^\pm} = \frac{12\lambda + 3\lambda^2}{31 + 12\lambda + 3\lambda^2 + \gamma(\frac{16}{3} + 4\lambda + \frac{8}{3}\lambda^2)} , \quad (2)$$

where $\gamma = \frac{4+4\lambda+\lambda^2}{5+5\lambda+3\lambda^2+\lambda^3}$. From the K/π ratio measurement we determine that

$$\lambda_{UA1} = 0.29 \pm 0.02 (stat) \pm 0.01 (syst) . \quad (3)$$

Our measurement is in good agreement with the world average value $\lambda = 0.29 \pm 0.02$ from previous measurements [9]. It is also in agreement with other collider experiments, eg., UA5 [10] and CDF [11]. If we combine our measurement and the existing world average, we obtain a new estimate of λ which is 0.29 ± 0.015 .

Figure 2: K/π ratio at different center of mass energies for: a) K_S^0 : $K/\pi = 2K_S^0/\pi^\pm$, b) $K^\pm$: $K/\pi = (K^+ + K^-)/\pi^\pm$. The line is a fit to UA1, UA5 [8], E735 [8] and CDF [11] data.

Fig. 2 shows the K/π ratio for different center of mass energies.[8] The fitting function was chosen to be of the form ($\sqrt{s}$ is in GeV units):

$$f(\sqrt{s}) = a + b \cdot \ln(\sqrt{s}). \quad (4)$$

where $a = 0.041 \pm 0.021$, $b = 0.009 \pm 0.003$ and with $\chi^2/NDF = 0.6$.

The K/π ratio shows a small increase with the center of mass energy $\sqrt{s}$. This is probably due to the fact that more gluons are produced at higher energy.

Fig. 3 shows the compilation of the measurements of the strangeness suppression factor λ [9] [10] [11].

Figure 3: The compilation of the measurements of the strangeness suppression factor as a function of $(\hat{s}_{eff})^{\frac{1}{2}}$ [9, 10, 11]. The solid line is a fit to the data above $(\hat{s}_{eff})^{\frac{1}{2}} = 1.0 \text{ GeV}$.

For hadron-hadron interactions, the effective centre of mass energy $\hat{s}_{eff}$ is given by the energy of the valence quark in the beam:

$$\hat{s}_{eff} = s < x_1 > < x_2 > \quad (5)$$

where $< x_1 >$ and $< x_2 >$ are the average momentum fractions of the beam valence quark or lepton and the target valence quark or lepton respectively.

The following two formulae are used to convert s to $\hat{s}_{eff}$ in pp , $p\bar{p}$ and πp interactions.
 $\sqrt{\hat{s}_{eff}(pp)} = \sqrt{\hat{s}_{eff}(p\bar{p})} = 0.11\sqrt{s}$ and $\sqrt{\hat{s}_{eff}(\pi p)} = 0.15\sqrt{s}$.
We have fitted this distribution with a function of the form:

$$\lambda = a + b \cdot \ln(\sqrt{\hat{s}_{eff}}). \quad (6)$$

Only data above $\sqrt{\hat{s}_{eff}} = 1 \text{ GeV}/c^2$ have been used to avoid any distortion of the fit due to threshold effects. We found that $a = 0.274 \pm 0.020$, $b = 0.0053 \pm 0.0059$ with $\chi^2/NDF = 0.68$. Both K/π and λ may show a tendency to increase slowly with $\sqrt{s}$ which could be due to the increase in radiation of gluons which then fragment into $s\bar{s}$ pairs. However, at this stage, the effect is not significant. Extrapolating to the LHC center of mass energy of 14 TeV we obtain $K/\pi \simeq 0.107 \pm 0.030$ and $\lambda = 0.31 \pm 0.05$.

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