Flavor Asymmetry in Hyperons and Drell-Yan Processes *

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Abstract

SU(3), baryon octets and a meson cloud model are compared for the flavor asymmetry of sea quarks in the Σ⁺, as an example. Large differences are found, especially between SU(3) and the meson cloud model. We suggest Drell-Yan measurements of Σ⁺ − p and Σ⁺ − d to test the prediction of various models. We use the meson cloud model to predict both valence and sea quark distributions.

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The predicted [1] and measured [2], [3] flavor asymmetry of the proton, e.g., \( \bar{d} / \bar{u} \) or \((\bar{d} - \bar{u})\), have awakened considerable interest. A simple explanation first proposed by A. Thomas [1] was in terms of the pion sea surrounding the quarks in the proton. Since a proton consists of \( uud \) quarks surrounded by a \( \pi^0 \) or \( udd \) quarks surrounded by a \( \pi^+ (ud\bar{d}) \), an excess of \( \bar{d} \) over \( \bar{u} \) is to be expected. This model has been examined quantitatively [4] and can explain the Gottfried sum rule deficiency [5] and the \((\bar{d} - \bar{u})\) measured in Drell-Yan p-p collisions [2], [3]. We have examined the expected flavor asymmetry of \( \Sigma^\pm \) baryons. [6] We find large differences between the expected asymmetry on (1) the basis of SU(3), (2) a baryon octet \( \otimes \) meson octet model, and (3) the meson cloud model. Thus, a measurement of the sea asymmetry via the Drell-Yan reactions \( \Sigma^\pm + p \rightarrow d \rightarrow l^+ + l^- + X \) can be used to differentiate between the models.

I will use the \( \Sigma^+ \) to illustrate the thesis. It is very easy to understand the difference between SU(3) and the meson cloud model. In SU(3) we have \( u\bar{u} \) in the \( p \Rightarrow u\bar{u} \) in the \( \Sigma^+ \), \( d\bar{d} \) in the \( p \Rightarrow s\bar{s} \) in the \( \Sigma^+ \), \( s\bar{s} \) in the \( p \Rightarrow d\bar{d} \) in the \( \Sigma^+ \). Thus, we have \( \frac{\bar{d}}{\bar{u}}(\Sigma^+) = \frac{s}{u}(p) \) in SU(3). On the other hand, one expects a larger \( \bar{d}/\bar{u} \) ratio in the \( \Sigma^+ \) than in the proton in the meson cloud model because \( \Sigma^+ \) can decompose into \( \Sigma^+ \pi^0, \Sigma^0 \pi^+, \Lambda^0 \pi^+, \) and \( p\bar{K}^0 \), where all but the first case (\( \Sigma^+ \pi^0 \)) correspond to an excess of \( \bar{d} \) quarks.

At \( x \sim 0.2 \), the measured ratio \( \bar{u}/\bar{d} \approx 1/2 \) [2] (or \( 2/3 \) [3]); also \( \frac{s}{u+a}(p) \approx 1/4 \). This gives \( \frac{\bar{d}}{\bar{u}}(\Sigma^+) = \frac{s}{u}(p) \sim 0.7 \) in SU(3); this value is < 1, in contrast to the meson cloud model.

We have also examined a proton made up of a baryon octet \( \otimes \) a meson octet with a ratio of SU(3) couplings \( F/D = 0.6 \). A summary is presented in table I for \( x \simeq 0.2 \).
TABLE I. Predicted and measured flavor ratios. The experimental column refers to the proton; all other ones are predictions for the $\Sigma^+$.  

| Flavor ratios | Experim. | SU(3) | Octets | Meson Cloud |
|---------------|----------|-------|--------|-------------|
| $\bar{u}/\bar{d}(p), \bar{d}/(\Sigma^+)$ | $\frac{1}{2}(\frac{2}{3})$ | $\frac{1}{2}(\frac{2}{3})$ | 0.29 | $\sim \frac{1}{2}$ |
| $\bar{s}/(u+d)(p), \bar{d}/(u+s)(\Sigma^+)$ | $\sim \frac{1}{4}$ | $\sim \frac{1}{4}$ | 0.42 | $\sim 0.1$ |
| $\bar{s}/(\Sigma^+)$ | ? | $\sim \frac{4}{3}$ | 0.54 | $\sim 0.3$ |
Deviations from SU(3) symmetry can also be expected in the distribution function of valence quarks [3]. For instance, on the basis of a quark-diquark model, we predict that \( \Delta u(\Sigma^+) \) is more than three times as large as the SU(3) value at \( x \sim 0.7 \).

Appropriate for this conference in honor of Josef Speth’s 60th birthday, we have used the Sullivan process to compute the valence and sea quark distribution functions in the \( \Sigma^+ \). We have

\[
\Sigma^+ = \sqrt{Z}[\Sigma^+_{\text{bare}} + \sum \int dyd^2k_\perp \phi_{BM}(y, k^2_\perp)B(y, \vec{k}_\perp)M(1-y, -\vec{k}_\perp)] ,
\]

with \( M = \pi^+, \pi^0, K^0 \) and \( B = \Lambda^0, \Sigma^0, \Sigma^+, p \).

We carry out our calculation in the infinite momentum frame with time ordered perturbation theory [4] and pseudoscalar coupling. We neglect masses above 1700 MeV and thus do not consider \( \Delta \bar{K} \) states. We have respected the necessary symmetries. [4] For instance, we have

\[
q(\Sigma^+, x) = \sqrt{Z}(q_{\text{bare}} + \delta q) ,
\]

with

\[
\delta q(\Sigma^+, x) = \sum \int_x^1 f_{BM}(y)q_M(x/y)\frac{dy}{y} + \int_x^1 f_{BM}(y)q_B(x/y)\frac{dy}{y} ,
\]

and require

\[
f_{MB}(y) = f_{BM}(y)
\]

In order to take finite sizes into account, we introduce Gaussian form factors with the size set by \( \Lambda = 1.08 GeV \) [4]. We have studied the dependence of our results on \( \Lambda \); the changes are quantitative, but not qualitative. Coupling constants are taken from Dumbrajs, Koch, and Pilkhun. [7] We assume that 20% of the mesons’ momenta are carried by sea quarks.

For the \( s \) quark distribution in the \( \bar{K}^0, \Lambda^0, \) and \( \Sigma \), we take both SU(3) and a shifted distribution which takes the higher mass of the \( s \) quark into account.
For the proton, we find that our calculation with the omission of the \( \Delta \) and higher mass (e.g., vector) mesons gives an acceptable fits for the \((\bar{d} - \bar{u})\) experimental data. However, \(\bar{d}/\bar{u}\) shows no decrease at higher values of \(x\), contrary to experiment; see, however [8].

The results of our calculation are shown in the following figures. Fig. 1 shows the momentum fraction carried by \(u\) and \(\bar{u}\) quarks; Figs. 2 and 3 are the same for \(s\) and \(d\) quarks; Figs. 4 and 5 show the valence quark momentum distributions. Figs. 6 and 7 show \(\bar{d}/\bar{u}\) and \((\bar{d} - \bar{u})\) distributions. Fig. 8 is the momentum fraction \(x(\bar{d} - \bar{u})\). Figs. 9 and 10 compare the \(\Sigma^+\) and proton \(\bar{r} \equiv \bar{d}/\bar{u}\) and \((\bar{d} - \bar{u})\). It is readily apparent that \((\bar{d} - \bar{u})\) is larger in the \(\Sigma^+\) than in the proton. The ratio \(\bar{r} \equiv \bar{d}/\bar{u}\) in the \(\Sigma^+\) vs. \(p\) is seen to begin at approximately 1 at small \(x\) and to climb to 2 at \(x \sim 0.35\).

In conclusion, the ratio \(\bar{r} \equiv \bar{d}/\bar{u}\) in the \(\Sigma^+\) may be < 1, as in (SU(3) or > 1 as in the meson cloud model. We have calculated both \(q(x)\) and \(\bar{q}(x)\) in the meson cloud model and have confirmed that \(\bar{r}(\Sigma^+) > \bar{r}(p)\) in this model.
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Fig. 2. Momentum fraction carried by sea $s$ and $\bar{s}$ quarks.

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