# NUCLEON-ANTINUCLEON ANNIHILATION AT REST IN A STATISTICAL QUARK MODEL

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Predictions of the statistical quark model are compared with existing data on multiplicity distributions of nucleon-antinucleon annihilation at rest. Reasonable agreement is found for both $p\bar{p}$ and $n\bar{p}$ annihilations.

## 1. Introduction

Nucleon-antinucleon annihilation at low kinetic energy has been recognized as a very convenient means of checking the predictions of various fireball models [1–4]. It is assumed that the process goes through formation and subsequent decay of a single fireball. This assumption is supported by the observed isotropy of angular distributions for annihilation at rest. For larger kinetic energies the assumption of single fireball dominance becomes worse, the angular distributions become anisotropic. The most reasonable comparison of a fireball model with data is therefore in annihilation at rest. However, it is clear that even in this case single fireball dominance can be justified only "a posteriori" by successful predictions and favourable comparison with experiment.

In this note predictions of the statistical quark model [5, 6] are worked out and compared with experimental multiplicity distributions of $N\bar{N}$ annihilation at rest. According to the model, a fireball decays into SU(3) multiplets of pseudoscalar, vector and tensor mesons. Thus there is hope that the ample resonance production in $N\bar{N}$ annihilation may be described by the model.

The organization of the paper is as follows. In Section 2 the statistical quark model is briefly reviewed. In Section 3 we discuss application of the model to annihilations and present predictions for multiplicity distributions. Section 4 contains a discussion of the results and some general comments on the application of statistical models to multiplicity distributions.

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## 2. *The statistical quark model*

The statistical quark model of fireball decay has been described previously [5, 6]. According to the model a (mesonic) fireball is characterized by quark and antiquark quantum numbers $q\bar{q}$. The quarks in the fireball emit mesons subsequently, statistically and independently of each other. Subsequent emission means that the decay proceeds in steps. In each step a single meson is emitted (by one of the quarks) with a probability proportional to the phase space of the emitted meson times the phase space of the fireball left after meson emission. In other words we have a statistical chain decay picture. At the end of the decay chain, when there is no more energy to emit mesons, the fireball transforms into an ordinary meson resonance.

The chain decay of the fireball is described by an integral equation[1]. The precise definition of the model is conveniently given by writing down the Laplace transformed integral equation. Thus our model is defined by

$$Z_{q\bar{q}} = D_{q\bar{q}}+\alpha \sum_{q'} D_{qq'}Z_{q'\bar{q}}+\alpha \sum_{\bar{q}'} Z_{q\bar{q}'}D_{\bar{q}'\bar{q}}-\alpha^2 \sum_{q',\bar{q}'} D_{qq'}Z_{q'\bar{q}'}D_{\bar{q}'\bar{q}}, \tag{1}$$

where $Zq\bar{q}$ is the "sum over states" of the fireball specified by the quark (antiquark) indices $q(\bar{q}), q(\bar{q}) = 1, 2, 3$ for $u(\bar{u}), d(\bar{d}), s(\bar{s})$ quarks (antiquarks).

$$D_{qq'} = \begin{pmatrix} PS_1+xV_1+yT_1 & 2(\pi_+ +x\varrho_+ +yA_{2+}) & 2(K_+ +xK_+^* +yK_{N+}) \\ 2(\pi_- +x\varrho_- +yA_{2-}) & PS_1+xV_1+yT_1 & 2(K_0+xK_0^*+yK_{N_0}) \\ 2(K_- +xK_-^* +yK_{N-}) & 2(\bar{K}_0+x\bar{K}_0^*+y\bar{K}_{N_0}) & PS_2+xV_2+yT_2 \end{pmatrix}, \tag{2}$$

with

$$PS_1 = \pi_0+\eta \cos^2 \varphi+\eta' \sin^2 \varphi, \qquad V_1 = \varrho_0+\omega,$$

$$T_1 = A_{20}+f' \cos^2 \psi+f \sin^2 \psi,$$

$$PS_2 = 2\eta \sin^2 \varphi+2\eta' \cos^2 \varphi, \qquad V_2 = 2\Phi,$$

$$T_2 = 2f' \sin^2 \psi+2f \cos^2 \psi,$$

$$\cos^2 \varphi = 0.721, \qquad \cos^2 \psi = 0.420, \tag{3}$$

where the "sum over states" of single hadrons are denoted by $\pi_0, \pi_+, \pi_-, \eta, \eta', \ldots$ $\varphi(\psi)$ is the pseudoscalar (tensor) mixing angle relative to the ideal mixing. For vector mesons ideal mixing was assumed. $\alpha$ is a characteristic cross section and the parameter $x(y)$ determines the frequency of vector (tensor) mesons relative to the pseudoscalar mesons.

SU(3) invariance is strictly taken into account in Eq. (1) at each decay step. Symmetry breaking is introduced by using the observed masses of resonances in the single hadron "sum over states". Spin, angular momentum and polarization effects are neglected.

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[1] The mathematical formulation of statistical chain decay is given e.g. in Refs [7, 8].

The solution of Eq. (1) is

$$Z_{q\bar{q}} = \left[\frac{D}{(1-D)^2}\right]_{q\bar{q}}, \tag{4}$$

which may be rewriten as

$$Z_{q\bar{q}} = \frac{[D'^2]_{q\bar{q}}}{(\det(1-D))^2} + \frac{D'_{q\bar{q}}}{\det(1-D)}, \tag{5}$$

where

$$D' = \begin{pmatrix} (PS_1-1)(PS_2-1)-4K_0\bar{K}_0 & 4\bar{K}_0K_+-2\pi_+(PS_2-1) & 4\pi_+K_0-2K_+(PS_1-1) \\ 4K_0K_--2\pi_-(PS_2-1) & (PS_1-1)(PS_2-1)-4K_-K_+ & 4\pi_-K_+-2K_0(PS_1-1) \\ 4\pi_-\bar{K}_0-2K_-(PS_1-1) & 4K_-\pi_+-2\bar{K}_0(PS_1-1) & (PS_1-1)^2-4\pi_-\pi_+ \end{pmatrix}. \tag{6}$$

To obtain the full $D'$ matrix the substitutions

$$PS_1 \to PS_1+xV_1+yT_1, \quad \pi_+ \to \pi_++x\varrho_++yA_{2+}, \text{ etc.} \tag{7}$$

should be made in Eq. (6). It is easy to write down the power expansion of $(\det(1-D))^{-k-1}$. It reads as

$$[\det(1-D)]^{-k-1} = \sum_{n_1,\dots,n_5=0}^{\infty} (-1)^k \prod_{i=1}^{5} \frac{1}{n_i!}$$
$$(4\pi_-\pi_+)^{n_1}(8K_0K_-\pi_++8\bar{K}_0K_+\pi_-)^{n_2}(4K_+K_-+4K_0\bar{K}_0)^{n_3}PS_2^{n_4}PS_1^{n_5}$$
$$\frac{(n_1+n_2+n_3+k)!(n_2+n_3+n_4+k)!}{(n_2+n_3+k)!}\,\frac{(2n_1+2n_2+n_3+2k+n_5+1)!}{(2n_1+2n_2+n_3+2k+1)!}. \tag{8}$$

To obtain the complete expansion the substitutions (7) should be carried out.

The multiplicity distribution $w_l$ is given by

$$w_l = cg_l\varrho^l(M),$$

where $\varrho^l(M)$ is the invariant phase space of the final state specified by $l$ ($l_i$ denote the numbers of type $i$ particles, $M$ is the mass of the fireball) and $g_l$ is determined by the expansion of $Z_{q\bar{q}}$ in terms of $z_i$ ($z_i$ are the "sum over states" of type $i$ particles):

$$Z_{q\bar{q}} = \sum_{l=0}^{\infty} g_l z_1^{l_1} z_2^{l_2} \dots .$$

$c$ is a normalization constant. Using formulae (5–8) the expansion may be carried out easily. We do not reproduce here the resulting formula as it is rather lengthy and not particularly instructive.

Assuming that multiparticle production in high energy collisions proceeds through clusters of the same type as our fireball, it is possible to get information on the parameters $x$ and $\alpha^2$. (For details of this procedure see Ref. [6]). Recent measurements [9] on $\varrho_0$ production determine $x$ to be about 4. (Note that SU (6) would predict $x = 3$). Assuming a maximal temperature (corresponding to the transverse momentum cut-off in high energy collisions) $T_0 = 180$ MeV, $\alpha$ may be determined in the model. We get $\alpha = 1.652\ \mathrm{GeV}^{-2}$ (for $x = 4$). A slightly higher temperature $T_0 = 188$ MeV yields $\alpha = 1.40\ \mathrm{GeV}^{-2}$. We shall give the model predictions for both values of $\alpha$. The parameter $y$ remains unspecified, thus we do not obtain useful predictions for tensor meson production.

### 3. *Application to $N\bar{N}$ annihilation*

The initial state in $N\bar{N}$ annihilation contains three quarks and three antiquarks. Thus it is not immediate to connect this state with a fireball containing one quark-antiquark pair.

The problem may be solved by invoking the quark rearrangement ideas of Refs [10, 11]. We assume that quarks and antiquarks of the initial state rearrange themselves into pairs, which form fireballs of the type described in the previous section. We also assume that the mass distribution of the three fireballs obtained by this mechanism is given by phase space. The multiplicity distribution of such a system can be determined from the product $Z_{q_1\bar{q}_1} \cdot Z_{q_2\bar{q}_2} \cdot Z_{q_3\bar{q}_3}$ of the "sum over states" of the individual fireballs. Allowing for annihilation of the initial quark-antiquark pairs, we also get two fireball and one fireball systems. Denoting by $\Omega$ the ratio of the probability of quark-antiquark annihilation to the probability of fireball formation we get for $p\bar{p}$ annihilation:

$$Z_{u\bar{u}}(Z_{u\bar{d}} \cdot Z_{d\bar{u}} + Z_{u\bar{u}} \cdot Z_{d\bar{d}}) + \Omega(Z_{u\bar{u}}(2 \cdot Z_{d\bar{d}} + Z_{u\bar{u}}) + Z_{u\bar{d}} \cdot Z_{d\bar{u}}) + \Omega^2(2 \cdot Z_{u\bar{u}} + Z_{d\bar{d}})$$

and for $n\bar{p}$ annihilation:

$$Z_{d\bar{u}}(Z_{d\bar{u}} \cdot Z_{u\bar{d}} + Z_{u\bar{u}} \cdot Z_{d\bar{d}}) + \Omega(Z_{u\bar{u}} + Z_{d\bar{d}})Z_{d\bar{u}} + \Omega^2 \cdot Z_{d\bar{u}}.$$

$\Omega$ is a parameter which may be fitted from experimental data. As statistical models are expected to be most reliable for high multiplicity channels, we have performed a fit to the frequencies of $n(\pi_+\pi_-)$, $n(\pi_+\pi_-)\pi_0$, $n(\pi_+\pi_-)$ + neutrals channels of $p\bar{p}$ annihilation ($n \geqslant 2$). It turned out that large values of $\Omega$ are preferred, i.e. we are left with the $(2Z_{u\bar{u}} + Z_{d\bar{d}})$ system for $p\bar{p}$ annihilation (and the $Z_{d\bar{u}}$ system for $\bar{p}n$ annihilation).

Another possibility is to assume that the quarks of the initial state annihilate and all the energy goes into a single fireball. In this case we get for $p\bar{p}$ annihilation:

$$Z_{u\bar{u}} + \beta Z_{d\bar{d}} + \gamma Z_{s\bar{s}}$$

and for $\bar{p}n$ annihilation: $Z_{d\bar{u}}$. While we have no free parameters for $\bar{p}n$ annihilation, we

[2] Alternatively, the parameters $x$ and $\alpha$ could be determined from $N\bar{N}$ annihilation data alone.

have two of them for $p\bar{p}$ annihilation. ($\beta(\gamma)$ determines the frequency of a single $d\bar{d}(s\bar{s})$ fireball formation relative to $u\bar{u}$ fireball formation.) However, for $p\bar{p}$ annihilation into pions (i.e. strange particles excluded) the contributions of $Z_{u\bar{u}}$ and $Z_{d\bar{d}}$ are the same (see Eqs (5.8)). Furthermore even assuming a large value for $\gamma$ ($\gamma = 1$), the contribution of $Z_{s\bar{s}}$ is less than 1%. Thus we may safely neglect the $s\bar{s}$ fireball. Then we are left without free parameters and the predictions coincide with those of the quark rearrangement model.

As stated above for $p\bar{p}$ annihilation into pions we arrive in both models to $Z_{u\bar{u}}$. The predictions are summarized in Tables I—III. For annihilation into strange particles predictions of the $Z_{u\bar{u}}+Z_{d\bar{d}}$ model are given in Table IV. Predictions for $\bar{p}n$ annihilation are the same in both models; they are listed in Tables V—VII. Available experimental data are also indicated in the Tables.

TABLE I

Branching ratios (in %) for $p\bar{p}$ annihilation into pions

| Channel | Experiment | | Model predictions | |
|---|---|---|---|---|
| | Ref. [12] | Ref. [14] | $T_0$ = 180 MeV | $T_0$ = 188 MeV |
| 0 prong | 3.6 ±0.6 | 3.4 ±0.5 | 1.29 | 1.42 |
| 2 prongs | 42.0 ±1 | 44.7 ±1.2 | 38.98 | 41.3 |
| $\pi_+\pi_-$ | 0.40±0.04 | 0.34±0.03 | 0.132 | 0.187 |
| $\pi_+\pi_-\pi_0$ | 7.3 ±0.4 | 8.2 ±0.4 | 3.67 | 4.68 |
| $\pi_+\pi_-MM$ | 34.4 ±0.8 | 36.2 ±1.3 | 35.18 | 36.45 |
| 4 prongs | 49.8 ±1. | 48.0 ±1.1 | 54.95 | 52.66 |
| $2\pi_+2\pi_-$ | 7.3 ±0.6 | 6.1 ±0.3 | 7.75 | 8.73 |
| $2\pi_+2\pi_-\pi_0$ | 20.8 ±0.7 | 19.6 ±0.9 | 26.2 | 25.9 |
| $2\pi^+2\pi^-MM$ | 21.6 ±0.8 | 22.3 ±1.2 | 21 | 18 |
| 6 prongs | 4.5 ±0.2 | 4.0 ±0.2 | 4.78 | 3.63 |
| $3\pi_+3\pi_-$ | 2.2 ±0.25 | 2.0 ±0.2 | 2.42 | 1.90 |
| $3\pi_+3\pi_-\pi_0$ | 1.95±0.15 | 1.7 ±0.3 | 2.0 | 1.50 |
| $3\pi_+3\pi_-MM$ | 0.3 ±0.1 | 0.3 ±0.1 | 0.36 | 0.23 |
| $\langle n_{\pi_-}+n_{\pi_+}\rangle$ | 3.10±0.05 | 3.05±0.04 | 3.26 | 3.15 |

TABLE II

Average number of $\pi_0$'s and $\gamma$'s versus number of negative pions for $p\bar{p}$ annihilation into pions

| $n_-$ | Experiment [12] | Model predictions | | | |
|---|---|---|---|---|---|
| | | $T_0$ = 180 MeV | | $T_0$ = 188 MeV | |
| | $\langle n_{\pi_0}\rangle$ | $\frac{1}{2}\langle n_\gamma\rangle$ | $\langle n_{\pi_0}\rangle$ | $\frac{1}{2}\langle n_\gamma\rangle$ | $\langle n_{\pi_0}\rangle$ |
| 0 | 4 ±0.5 | 4.05 | 3.79 | 3.94 | 3.67 |
| 1 | 2.5 ±0.3 | 2.53 | 2.45 | 2.45 | 2.35 |
| 2 | 1.4 ±0.2 | 1.31 | 1.31 | 1.25 | 1.24 |
| 3 | 0.6 ±0.05 | 0.56 | 0.56 | 0.54 | 0.54 |
| $\langle n_{\pi_0}\rangle$ | 1.91±0.23 | 1.79 | 1.73 | 1.75 | 1.71 |

TABLE III

Frequency of some exclusive channels (in %) for $p\bar{p}$ annihilation into pions

| Channel | Experiment | | Model predictions | |
|---|---|---|---|---|
| | Ref. [14] | Ref. [15] | $T_0$ = 180 MeV | $T_0$ = 188 MeV |
| $\omega\pi_+\pi_-$ [a] | 3.8 ±0.4 | | 3.52 | 4.4 |
| $\eta\pi_+\pi_-$ [a] | 1.2 ±0.3 | | 1.03 | 1.27 |
| $\varrho_0\pi_+\pi_-$ [a] | $5.8\ {}^{+0.3}_{-1.3}$ | | 3.34 | 4.53 |
| $\varrho_0\pi_+\pi_-\pi_0$ | 7.3 ±1.7 | 4.50±0.6 | 5.32 | 5.44 |
| $\varrho_\pm\pi_\mp\pi_+\pi_-$ | 6.4 ±1.8 | 6.7 ±0.7 | 7.08 | 7.25 |
| $\varrho_0\pi_0$ | 1.4 ±0.2 | 5.8 ±0.32 | 0.22 | 0.3 |
| $\varrho_\pm\pi_\mp$ | 2.9 ±0.4 | | 0.88 | 1.25 |
| $\varrho_0\varrho_0$ | 0.4 ±0.3 | 0.12±0.12 | 0.30 | 0.43 |
| $\omega\varrho_0$ | 0.7 ±0.3 | 1.88±0.3 | 0.59 | 0.85 |
| $\eta\varrho_0$ | 0.22±0.17 | 0.41±0.08 | 0.14 | 0.19 |
| $\varrho_+\varrho_-$ | | 0.6 ±0.2 | 1.17 | 1.73 |
| $\varrho_0\pi_+\pi_-(\delta_0^0$ and $\delta_0^2)$ | | 3.8 ±0.3 | 2.91 | 3.66 |
| $\omega\delta_0^0$ | | 2.93±0.3 | 2.81 | 3.53 |
| $\eta\delta_0^0$ | | 0.52±0.1 | 0.85 | 1.08 |
| $\eta\pi_+\pi_+\pi_-\pi_-$ | | 1.46±0.16 | 0.90 | 0.81 |
| $\omega\pi_+\pi_+\pi_-\pi_-$ | | 0.7 ±0.1 | 0.73 | 0.66 |
| $\omega\omega$ | | 1.4 ±0.6 | 0.28 | 0.43 |
| $\varrho_0\varrho_\pm\pi_\mp$ | | 2.35±0.7 | 1.49 | 1.80 |
| $\varrho_0\varrho_0\pi_0$ | | $<0.5\cdot10^{-1}$ | 0.18 | 0.22 |

[a] $\pi_+\pi_-$ may come from $\varrho_0$ decay.

TABLE IV

Branching ratios (in %) of strange channels for $p\bar{p}$ annihilation

| | Experiment [16] | Model prediction | |
|---|---|---|---|
| | | $T_0$ = 180 MeV | $T_0$ = 188 MeV |
| $K_0\bar{K}_0$ | 0.093±0.003 | 0.052 | 0.070 |
| $K_+K_-$ | 0.128±0.017 | 0.052 | 0.070 |
| $\bar{K}^*K+\bar{K}K^*$ | 0.36 ±0.04 | 0.64 | 0.87 |
| $K^*\bar{K}^*$ | 0.12 ±0.03 | 0.61 | 0.82 |
| $K\bar{K}\pi$ | ≈0.44 | 1.34 | 1.02 |
| $K^*K\pi$ | ~1.0 | 2.29 | 1.75 |
| $K\bar{K}\varrho$ | 0.40 ±0.06 | 0.11 | 0.18 |
| $K_0\bar{K}_0\omega$ | 0.23 ±0.014 | 0.02 | 0.02 |
| $K_+K_-\omega$ | 0.21 ±0.013 | 0.02 | 0.02 |
| $K_0\bar{K}_0\eta$ | 1.74 | 0.057 | 0.065 |
| $K_+K_-\eta$ | 0.164 | 0.057 | 0.065 |
| All strange channels | 5.75 | 7.9 | 8.6 |

TABLE V

Branching ratios (in %) for $\bar{p}n$ annihilation into pions

| Channel | Experiment | | Model predictions | |
|---|---|---|---|---|
| | Ref. [17] | Ref. [14] | $T_0$ = 180 MeV | $T_0$ = 188 MeV |
| 1 prong | 16.4±0.5 | | 11.46 | 12.54 |
| $\pi_-\pi_0$ | ⩽0.7 | 0.75±0.15 | 0.16 | 0.24 |
| $\pi_-MM$ | | 16.9 ±0.7 | 11.3 | 12.3 |
| 3 prongs | 59.7 ±1.2 | | 64.23 | 65.98 |
| $2\pi_-\pi_+$ | 1.57±0.21 | 2.3 ±0.3 | 1.91 | 2.4 |
| $2\pi_-\pi_+\pi_0$ | 21.8 ±2.2 | 17 ±2 | 19.98 | 22.9 |
| $2\pi_-\pi_0MM$ | | 39.7 ±2 | 42.34 | 40.7 |
| 5 prongs | 23.4 ±0.7 | | 23.8 | 20.7 |
| $3\pi_-2\pi_+$ | 5.17±0.47 | 4.2 ±0.2 | 7.59 | 7.2 |
| $3\pi_-2\pi_+\pi_0$ | 15.1 ±1.0 | 12 ±1 | 11.8 | 10.3 |
| $3\pi_-2\pi_+MM$ | | 6.6 ±1 | 4.3 | 3.3 |
| 7 prongs | 0.39±0.07 | 0.35±0.03 | 0.42 | 0.27 |
| $\langle n_{\pi_-}+n_{\pi_+}\rangle$ | 3.15±0.03 | 3.15±0.03 | 3.23 | 3.16 |
| $\langle n_\gamma\rangle$ | | | 3.59 | 3.53 |

TABLE VI

Frequency of some exclusive channels (in %) for $\bar{p}n$ annihilation into pions

| Channel | Experiment | | Model predictions | |
|---|---|---|---|---|
| | Ref. [17] | Ref. [18] | $T_0$ = 180 MeV | $T_0$ = 188 MeV |
| $\omega\pi_-\pi_-\pi_+$ | 12.0 ±3.0 | 6.3 ±0.8 | 3.3 | 3.4 |
| $\varrho_0\pi_-$ | 0.63 | 0.65±0.05 | 0.44 | 0.63 |
| $\varrho_0\pi_-\pi_0+\varrho_\mp\pi_\pm\pi_-$ | 8.7 | | 9.16 | 11.1 |
| $\eta\pi_-$ | ⩽0.25 | <0.2 | 0.09 | 0.12 |
| $\omega\pi_-$ | 0.48±0.08 | 0.33±0.05 | 0.44 | 0.63 |

TABLE VII

Frequency of some exclusive strange channels (in %) for $\bar{p}n$ annihilation

| Channel | Experiment Ref. [19] | Model predictions | |
|---|---|---|---|
| | | $T_0$ = 180 MeV | $T_0$ = 188 MeV |
| $K_0K_-$ | 0.15 ±0.02 | 0.10 | 0.15 |
| $K_0K_-\pi_0$ | 0.36 ±0.04 | 0.66 | 0.84 |
| $K_0\bar{K}_0\pi_-$ | 0.51 ±0.05 | 0.66 | 0.84 |
| $\bar{K}_0K_+\pi_-\pi_-$ | 0.25 ±0.03 | 1.18 | 1.33 |
| $K_0K_-\pi_+\pi_-$ | 0.34 ±0.04 | 1.17 | 1.34 |
| $\bar{K}_0K_+\pi_-\pi_-\pi_0$ | 0.016±0.01 | 0.17 | 0.16 |
| $K_0K_-\pi_-\pi_+\pi_0$ | 0.33 ±0.1 | 0.29 | 0.29 |
| $K_0\bar{K}_0\pi_-\pi_-\pi_+$ | 0.075±0.03 | 0.15 | 0.14 |
| All strange channels | | 7.4 | 9 |

## 4. *Discussion*

The predictions presented in Tables I—VII should not be all taken equally seriously. Due to the statistical character of the model it is clear that the best agreement is expected for high multiplicity channels and averaged quantities. Thus Tables I and V may be taken as the most reliable comparison of the model with experimental data. It is seen that for higher multiplicities agreement is good.

Table II presents the prong number dependence of average neutral pion number. Since these are averaged quantities, good agreement is expected. Though this is indeed the case, one should not exaggerate the importance of it. Namely, the experimental data are not directly measured (they are results of a fit to the histograms of multineutral channels calculated with ad hoc matric elements). We have given the average number of neutral pions (directly produced as well as decay product pions) and also the half of the average number of $\gamma$'s (which would be relevant if neutral pions were directly detected through the $2\gamma$ decay). It is seen that both of our predictions are within the error bars of experiment. The average numbers of pions given in Tables I, II were calculated taking into account the experimental branching ratios of resonance decay. Thus electromagnetic isospin breaking in resonance decay is reflected in our predictions, which leads e.g. to the excess of neutral pions (over charged pions).

Tables III, VI and part of Tables IV, VII present predictions for exclusive channel frequencies. It is clear that we should not expect good agreement here. In fact the rough agreement of (most of) our predictions with data is rather surprising. To underline this point, we present some remarks which apply quite generally to statistical models which neglect angular momentum conservation.

It is generally believed that $p\bar{p}$ annihilation at rest proceeds mainly through the initial $s$ state. If this is true e.g. states with two equal pseudoscalar particles are forbidden by angular momentum and parity. However nothing forbids these states in a statistical model. (In our model the trouble is not serious as our predicted numbers are small, E.g. for $2\pi_0$ we predict $3.16 \cdot 10^{-4}$ ($4.5 \cdot 10^{-4}$) to be compared with the experimental $4.8 \cdot 10^{-4}$ [13].) Clearly similar problems are less serious for high multiplicity channels. However, there is an angular momentum problem, which persists even for high multiplicities. It is easy to see that the relative angular momentum of $K_0$ and $\bar{K}_0$ determines whether a $K_0\bar{K}_0$ pair in a many particle state is a $K_S K_L$ or a $K_S K_S + K_L K_L$ state. In a statistical model it is then not possible to distinguish these possibilities, which severly restricts the predictive power of these models.

In summary, we believe that Tables I—VII prove that the statistical quark model yields a reasonable description of $N\bar{N}$ annihilation at rest. Some further improvements of the model are conceivable. E.g. inclusion of the finite width of resonances, of angular momentum conservation would be clearly neccessary. While the former is staightforward, the latter seems to be a very difficult problem.

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