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PRODUCTION OF ϕ-MESONS IN $\bar{N}N$-ANNIHILATION

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1 Introduction

Recent results from the LEAR experiments on the ϕ-meson production in the annihilation of stopped antiprotons have demonstrated a significant (by a factor of 30-50) violation of the Okubo-Zweig-Iizuka (OZI) rule. This semi-phenomenological rule was nicely confirmed in a number of experiments with pp, πp and $\bar{p}p$ interaction at different projectile energies. So the new LEAR results look really rather unusual and surprising. A number of theoretical models were invoked for the explanation of these data. It is interesting that the approaches based on the traditional conceptions seem to be unable to reproduce all features of the ϕ production observed now. At the same time unconventional ideas like polarized intrinsic strangeness in the nucleon offer rather natural explanation of the observed facts and propose a number of new effects to be measured.

To start discussion on the OZI rule violation it is useful to remind the very essence of this rule [1]. Let us consider, following Okubo [2], creation of qq states in the interaction of hadrons

$$A + B \longrightarrow C + q\bar{q} \quad \text{for q=u,d,s} \tag{1}$$

where hadrons A, B and C consist of only light quarks.

The OZI rule demands

$$Z = \frac{\sqrt{2}M(A + B \to C + s\bar{s})}{M(A + B \to C + u\bar{u}) + M(A + B \to C + d\bar{d})} = 0 \tag{2}$$

where $M(A + B \to C + q\bar{q})$ are the amplitudes of the corresponding processes.

It means that if the ϕ meson was a pure $\bar{s}s$ state, it could not be produced in the interaction of ordinary hadrons. The OZI rule strictly forbids creation of new flavors confined in only one particle. They (quarks with new flavors) must be shared among different particles.

However, the ϕ and ω are mixtures

$$\phi = \cos\Theta\ \omega_8 - \sin\Theta\ \omega_1 \tag{3}$$

$$\omega = \sin\Theta\ \omega_8 + \cos\Theta\ \omega_1 \tag{4}$$

of SU(3) singlet ω_1 and octet ω_8

$$\omega_8 = (u\bar{u} + d\bar{d} - 2s\bar{s})/\sqrt{6} \tag{5}$$

$$\omega_1 = (u\bar{u} + d\bar{d} + s\bar{s})/\sqrt{3} \tag{6}$$

and the ϕ could be created in the hadron interaction due to small admixture of the light quarks in its wave function.

Then the OZI rule Eq. (2) could be re-written in terms of physical ϕ and ω

$$\frac{M(A+B\to C+\phi)}{M(A+B\to C+\omega)} = -\frac{Z+\tan(\Theta-\Theta_i)}{1-Z\tan(\Theta-\Theta_i)} \tag{7}$$

here Θ and Θ_i are physical and ideal mixing angles, $\Theta_i = 35.3^0$.

From this equation one can immediately see that if OZI rule Eq. (2) is fulfilled and the parameter Z is equal to zero , then

$$R = \frac{\sigma(A+B\to \phi X)}{\sigma(A+B\to \omega X)} = \tan^2(\Theta-\Theta_i)\cdot f \tag{8}$$

here f is a kinematical phase space factor.

Since the vector mesons are practically ideally mixed, the difference $\delta = \Theta - \Theta_i$ is small: the mixing angle from the quadratic Gell-Mann-Okubo mass formula is $\Theta = 39^0$ and from the linear one it is $\Theta = 36^0$. Substituting these values in Eq. (8) one could obtain for $f = 1$:

$$R = 4.2\cdot 10^{-3} \quad \text{for quadratic mass formula} \tag{9}$$

$$R = 0.15\cdot 10^{-3} \quad \text{for linear mass formula} \tag{10}$$

As is clear from Eq. (7), the smallness of the ϕ/ω ratio is due to the OZI rule demand $Z = 0$ and perfect mixing of vector mesons $\delta = \Theta - \Theta_i \approx 1 - 3^0$. Another situation exists, for instance, for the tensor or pseudoscalar mesons, where mixing is not so perfect and the difference δ is large. In principle, under violation of the OZI rule one could imply the physical reasons which provide the deviation of the corresponding physical angle from the mixing one. But here we will consider the violation of the OZI rule at a pure phenomenological level as a deviation of the measured ϕ/ω ratios from the prediction of Eq. (9).

In Fig.1 the ratio $R = \phi X/\omega X$ multiplied by 10^3 for different reactions of pp, πp and $\bar{p}p$ interaction at different momenta is plotted.

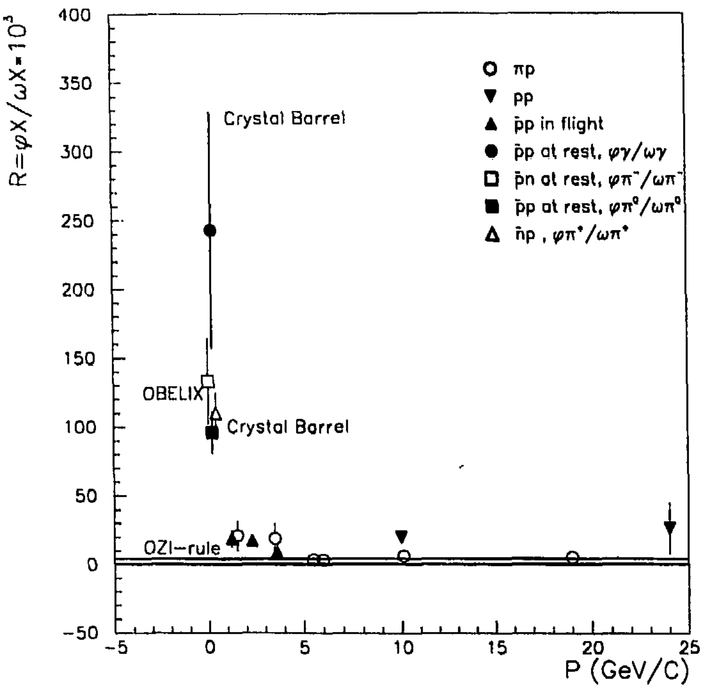

Figure 1: The ratio $R = \phi X/\omega X \cdot 10^3$ for different reactions of pp, πp and $\bar{p}p$ interaction at different momenta.

One could immediately realize that there is no problem with the OZI rule for pp, πp interactions and $\bar{p}p$ annihilation in flight. The deviation from the OZI prediction Eq. (9) is no more than 10%. However, for $\bar{p}p$ annihilation at rest the violation of the OZI rule is rather dramatic. In terms of the parameter Z from Eq. (2) the experiments with stopped antiprotons give

$$|Z| \approx 0.2 - 0.4$$

Naturally, the questions arise:
- why, among all hadronic interactions, is the ϕ production in antiproton annihilation at rest so large and the violation of the OZI rule so substantial?
-what are the physical reasons for strong OZI rule violation in $\bar{p}p$ annihilation at rest?

It is these questions that we will discuss in detail. In Sect.2 the review of the experimental data on ϕ production in $\bar{p}p$ annihilation at rest is given. Sect.3 is devoted to the theoretical models which are on the market for explanation of the strong OZI rule violation. Concluding Sect.4 is dedicated to the future experiments which could shed some light on the physical reasons for the OZI rule violation.

2 Experimental data on ϕ production in $\bar{p}p$ annihilation at rest

The existing experimental data on ϕ production in the annihilation of stopped antiprotons are summarized in Table 1.

Table 1. The ratios $R = \phi X/\omega X$ for production of the ϕ and ω - mesons in antinucleon annihilation at rest. The parameter Z of the OZI rule violation is calculated for $\delta = \Theta - \Theta_i = 3.7^0$, assuming identical phases of the ϕ and ω production amplitudes. The data are given for annihilation in a liquid hydrogen target (percentage of annihilation from P-wave is $\sim$ 10 – 20%), gas target (~60% P-wave) and LX-trigger [4] (~86-93% P-wave).

Final state	Initial states	$B.R.\cdot 10^4$	$R\cdot 10^3$	$\lvert Z\rvert$ (%)	Comments
$\phi\gamma$	${}^1S_0, {}^3P_J$	0.17 ± 0.04	243 ± 86	42 ± 8	liquid,[3]
$\phi\pi^0$	${}^3S_1, {}^1P_1$	5.5 ± 0.7	96 ± 15	24 ± 2	liquid,[3]
$\phi\pi^0$		1.9 ± 0.5			gas, [4]
$\phi\pi^0$		0.0 ± 0.3			LX-trigger, [4]
$\phi\pi^-$	${}^3S_1, {}^1P_1$	9.0 ± 1.1	83 ± 25	22 ± 4	liquid,[5]–[8]
$\phi\pi^-$		14.8 ± 1.1	133 ± 26	29 ± 3	$\bar{p}d$, $p < 200$ MeV/c, [9]
$\phi\pi^-$			113 ± 30	27 ± 4	$\bar{p}d$, $p > 400$ MeV/c, [9]
$\phi\pi^+$			110 ± 15	26 ± 2	$\bar{n}p$, [10]
$\phi\eta$	${}^3S_1, {}^1P_1$	0.9 ± 0.3	6.0 ± 2.0	1.3 ± 1.2	liquid,[3]
$\phi\eta$		0.37 ± 0.09			gas, [4]
$\phi\eta$		0.41 ± 0.16			LX-trigger, [4]
$\phi\rho$	${}^1S_0, {}^3P_J$	3.4 ± 0.8	6.3 ± 1.6	1.4 ± 1.0	gas, [4]-[11]
$\phi\rho$		4.4 ± 1.2	7.5 ± 2.4	2.1 ± 1.2	LX-trigger, [4]-[11]
$\phi\omega$	${}^1S_0, {}^3P_{0,2}$	6.3 ± 2.3	19 ± 7	7 ± 4	liquid, [12]-[13]
$\phi\omega$		3.0 ± 1.1			gas, [4]
$\phi\omega$		4.2 ± 1.4			LX-trigger, [4]
$\phi\pi^0\pi^0$	${}^{1,3}S_{0,1}, {}^{1,3}P_J$	1.2 ± 0.6	6.0 ± 3.0	1.3 ± 2.0	liquid,[3]
$\phi\pi^-\pi^+$		4.6 ± 0.9	7.0 ± 1.4	1.9 ± 0.8	liquid,[14]
ϕX, $X = \pi^+\pi^-, \rho$		5.4 ± 1.0	7.9 ± 1.7	2.4 ± 1.0	gas, [4]-[11]
ϕX, $X = \pi^+\pi^-, \rho$		7.7 ± 1.7	11.0 ± 3.0	4.0 ± 1.4	LX-trigger, [4]-[11]

From the data in this Table one could see that the strong OZI rule violation was observed in the experiments of three collaborations at LEAR: ASTERIX, OBELIX and Crystal Barrel. It was seen in the following channels:

$$\bar{p} + p \rightarrow \phi + \gamma \qquad (11)$$

$$\bar{p} + p \rightarrow \phi + \pi^0 \qquad (12)$$

$$\bar{n} + p \rightarrow \phi + \pi^+ \qquad (13)$$

$$\bar{p} + n \rightarrow \phi + \pi^- \qquad (14)$$

for annihilation in liquid and gas hydrogen and deuterium targets. The values of the ϕ/ω ratio are significantly higher than the OZI rule predictions. The highest deviation is for the $\phi\gamma$ channel where $R(\phi/\omega) \cdot 10^3 = 243 \pm 86$, i.e. about 50 times larger than the OZI prediction $R(\phi/\omega) \cdot 10^3 = 0.15 - 4$.

So the very existence of the strong deviation from the OZI rule in the annihilation of stopped antiprotons is a firmly established experimental fact seen by different groups in different reactions.

At the same time it is important to stress that not all chanells of ϕ production in $\bar{p}p$ annihilation at rest exhibit violation of the OZI rule. There are no problems with OZI for $\phi\eta$, $\phi\rho$, $\phi\omega$ and $\phi\pi\pi$ channels. The ϕ/ω ratio for different channels of $\bar{p}p$ annihilation at rest is shown in Fig.2.

It is interesting that the OZI rule violation strongly depends on the quantum numbers of the initial state. The conservation of P and C–parities strictly fix the possible quantum numbers of the $N\bar{N}$ initial state in binary reactions of ϕ production. The allowed initial states are listed in Table 1. Thus, the $\phi\pi$ final state is possible either from the spin triplet $^3S_1$ state, or from the spin singlet $^1P_1$ state. The ASTERIX collaboration observed [4] that $\phi\pi$ channel from the $^3S_1$ initial state has the branching ratio $B.R.(\bar{p}p \rightarrow \phi\pi^0) = (4.0 \pm 0.8) \cdot 10^{-4}$ and the ratio $R = \phi/\omega \cdot 10^3 = 76.9 \pm 17.1$. However no ϕ's at all were seen in the same channel for annihilation from the $^1P_1$ initial state!

Large difference in $\phi\pi$ production for annihilation from S and P–waves is a very important feature of ϕ production in $N\bar{N}$ annihilation. The key

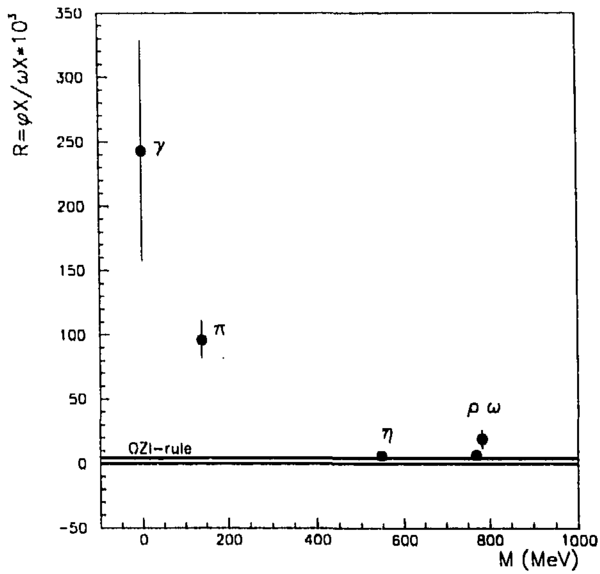

Figure 2: The ratio $R = \phi X/\omega X \cdot 10^3$ for different reactions of $\bar{p}p$ annihilation at rest as a function of mass M of the system X.

to the understanding of the nature of OZI rule breaking may be provided by the explanation of this experimental fact.

From inspection of Fig.2 where $\phi X/\omega X$ ratios for different channels of $\bar{p}p$ annihilation at rest are shown, one may conclude that the degree of the OZI violation increases with decreasing mass of the system X produced with the ϕ meson. Indeed, the strongest deviation occurs for $X = \gamma$ and π. A decrease in the mass of X means an increase in the momentum transfer to ϕ. The dependence of the ratios $\phi X/\omega X$ on the momentum transfer t between ϕ and $\bar{p}$ is plotted in Fig.3.

However one should be cautious to interpret the dependence in Fig.3

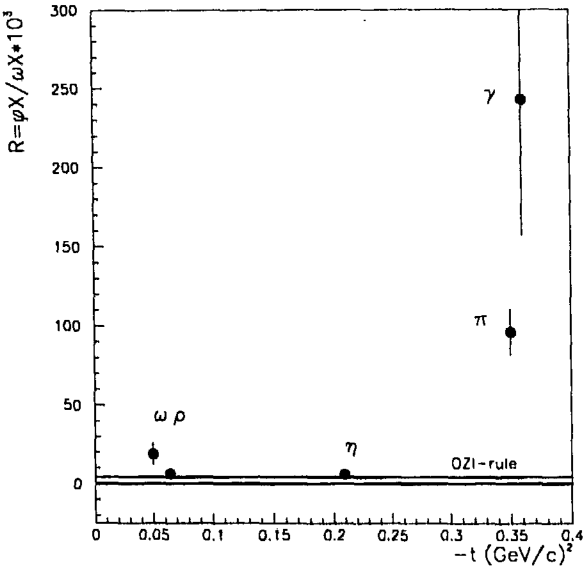

Figure 3: The ratio $R = \phi X/\omega X \cdot 10^3$ for different reactions of $\bar{p}p$ annihilation at rest as a function of ϕ momentum transfer.

as a proof that the OZI rule violation does increase with the momentum transfer. In binary reactions of antiproton annihilation at rest $\bar{p}p \to \phi(\omega) + X$ the momentum transfer to ω is always higher than the momentum transfer to ϕ. However, to find the t-dependence one should compare ϕ and ω production at the same momentum transfers. It is possible for annihilation in flight or in $\phi(\omega)\pi\pi$ channels for annihilation at rest.

It is important to realize that the typical momentum transfers in ϕ production of stopped antiprotons are rather small, no more than $|t| \leq 0.36$ $(GeV/c)^2$. So at LEAR we are far from the region of the deep inelastic lepton scattering experiments which probed the strangeness content of the nucleon quark sea.

It is interesting that the same increase of the ϕ/ω ratio with momentum transfer was also seen in $\pi p \to \phi(\omega)N$ reactions at 6 GeV/c [15].

An interesting result was reported by the Crystal Barrel collaboration [16] which measured the $\phi\pi$ cross section for antiproton annihilation in flight. The production rate of the $\phi\pi$ at 600 MeV/c is about 5 times smaller than at rest whereas the production rate of the K^*K remains constant. It may indicate that the degree of the OZI rule violation decreases with the energy, however direct measurements of the $\omega\pi$ reaction for annihilation in flight are needed.

Let us sum up the present experimental facts on the ϕ production in $\bar{p}p$ annihilation at rest:

- Large violation of the OZI rule prediction (9) exists in the $\phi\gamma$ and $\phi\pi$ channels whereas in other modes there is no significant deviation from the OZI rule prediction.
- Strong dependence on the quantum numbers of the initial state was seen for the $\phi\pi$ channel which is suppressed for annihilation from P-wave.
- Indication of the dependence of the degree of OZI rule violation on the momentum transfer exists.
- The deviation from the OZI rule prediction seems to diminish with the antiproton energy.

Any model to be used for explaining the large rate of ϕ production in $\bar{p}p$ annihilation at rest should be able to reproduce these experimental facts.

3 The models of OZI rule violation

All models of the OZI rule violation in annihilation of antiprotons assume that the OZI rule Eq. (2) itself is valid. The violation is only apparent and could be regarded as a signal of non-trivial dynamics of the processes considered.

3.1 Subthreshold resonance(s)

It has been suggested [18] that the enhancement of ϕ meson production in certain $\bar{N}N$ annihilation channels might be due to resonances. Thus, if there existed resonance in a $\phi\pi$ system close to the $\bar{N}N$ threshold, it might be possible to explain the selective enhancement of the $\phi\pi$ yield in S-wave annihilation, and the relative lack of ϕ's in P-wave annihilation. The best candidate for such a state is the so-called C-meson with mass $M = 1480 \pm 40$ MeV, width $\Gamma = 130 \pm 60$ MeV and quantum numbers $I = 1$, $J^{PC} = 1^{--}$, which was observed [19] in the $\phi\pi^0$ mass spectrum in the reaction $\pi^- p \to K^+ K^- \pi^0 n$ at 32.5 GeV/c.

However, this resonance cannot explain the enhancement in the $\phi\gamma$ channel, which is a final state with different quantum numbers. Moreover, it was predicted [18] that an isoscalar partner of the C-meson should exist. This state should couple to the $\phi\eta$ channel and induce the deviation from the OZI rule prediction. However neither the state itself, or any OZI rule violation was detected in $\phi\eta$ channel (see Table 1).

Direct search for the C meson in $\bar{p}p$ annihilation was unsuccessful. The ASTERIX collaboration [4] has established an upper limit of $3 \cdot 10^{-5}$ on the production of $\phi\pi^{\pm}$ resonance in $\bar{p}$ annihilation in a gas hydrogen target, and the Crystal Barrel collaboration has not seen the C-meson among $\phi\pi^0\pi^0$ final states [20].

So the explanation of the OZI rule violation as a manifestation of subthreshold resonances looks very doubtful.

3.2 Final state interactions

It has been suggested [21],[22] that the ϕ mesons production might be due to final-state interactions, such as

$$\bar{p}p \to K^* K \to \phi\pi \tag{15}$$

$$\bar{p}p \to \rho^+\rho^- \to \phi\pi \tag{16}$$

So the OZI–forbidden reaction is treated as a two–step process, where the OZI rule is fulfilled at each step.

The concrete calculations of different branching ratios were performed in the on-shell approximation. The results obtained are compared with the experimental data in Table 2.

Table 2. Branching ratios of different ϕ channels calculated by [23] (LLZ) and [22] (BL).

Final state ($B.R.\cdot 10^4$)	LLZ	BL	Experiment
$\Phi\pi^0$	0.6-2.9	2.9 ± 0.2	5.5 ± 0.7
$\Phi\pi^-$		7.2 ± 0.5	14.8 ± 1.1
$\Phi\gamma$	0.36-2.0	0.014	0.17 ± 0.04
$\Phi\eta$		0.3 ± 0.1	0.94 ± 0.28
$\Phi\rho$		0.063	3.4 ± 0.8
$\Phi\omega$		0.08	5.3 ± 2.2

One could see that the theoretical calculations missed the experimental values by a factor of 2-6 or more. All these calculations were made in the on-shell approximation, whereas recent [24] full calculations of the corresponding triangle diagrams, with consideration for the off-shell contributions, have shown that disagreement with experimental data only increases.

There are different opinions as to whether one should consider the above-mentioned results a failure or a success of the final-state interactions models (see, for instance, [23]). But the main problem of this approach is to prove why just this state (or a pair of states) should be chosen, and why contributions of all other hadronic loops could not cancel out these particular doorway states (see for discussion [25]).

To illustrate the difficulties of the rescattering model, let us consider recent calculations[23] of the $\phi\pi^+\pi^-$ channel. As is seen from Table 1, there is no violation of the OZI rule in this channel. In the rescattering scheme it may occur via the $K^*\bar{K}^*$ doorway state. The production rate of $K^*\bar{K}^*$ is large, comparable with the production rate of $K^*\bar{K}$. But the K^*K intermediate state should explain strong violation of the OZI rule in $\phi\pi$ channel. Why then is the OZI rule not violated in the $\phi\pi\pi$ channel, where a strong $K^*\bar{K}^*$ intermediate channel exists? This question was pointed out in [26]. Now the calculations [23] show that already including the $\omega\rho$ intermediate state $\bar{p}p \to \omega\rho \to \phi\pi\pi$ provides a production rate comparable with the experimental one. Therefore taking into account the $K^*\bar{K}^*$ intermediate state may lead to overestimation of the experimental value. But this at first glance obvious conclusion may be wrong due to interference between $\omega\rho$ and $K^*\bar{K}^*$ diagrams, which may produce any result.

Therefore, to prove the reliability of the rescattering model not only some production rates should be calculated but also such distinctive features of ϕ production as energy dependence or dependence on the momentum transfer should be explained.

The suppression of the $\phi\pi$ yield from P-wave annihilation could be accomodated in this model [27] simply as a result of the interference between two amplitudes with relative angular momenta l between ϕ and π equal $l = 0$ and 2. Then the ratio $R_P = B.R.(\phi\pi^0)_{1P_1} / B.R.(K^{*+}K^-)_{1P_1}$ could be within the 0.02 – 0.67 interval, if there is no hierarchy between $l = 0$ and $l = 2$ amplitudes. In the case of dominance of one amplitude, the ratio R_P is around 0.5.

An interesting result was obtained in [27] where production of f_2' in the $\bar{p}p \to f_2'\pi^0$ reaction was considered via final state interactions of K^*K and $\rho\pi$. The calculated production rates of f_2' from the S or P states are rather small, about 10^{-6}. It means that if any violation of the OZI rule will be established for f_2' it could not be explained due to rescattering.

For success of the rescattering models it is important that the $\bar{p}p \to K^*\bar{K}$ amplitude has "right" isospin dependence. Namely, the channel with isospin I=1 should be dominant to provide maximum coupling with the $\phi\pi$ final state. Old bubble chamber data (for instance, [28]) do demonstrate the dominance of I=1 $\bar{p}p \to K^*\bar{K}$ amplitude for annihilation in the S- wave. It is a task for the data analysis of high statistics experiments at LEAR to confirm this result for the S-wave annihilation and to test what is the isospin dependence of $\bar{p}p \to K^*K$ from the P-wave. If I=1 dominance also exists for annihilation from P–wave, then it is not clear how to accomodate this fact with $\phi\pi$ suppression in P–wave.

3.3 Polarized intrinsic nucleon strangeness

It was assumed [29]-[30] that the abundant ϕ meson production could be the consequence of an admixture of $\bar{s}s$ pairs in the nucleon. At first glance, the intrinsic strangeness of the nucleon should lead to the same enhancement of the ϕ production in all annihilation channels. That is contrary to the experimental data.

An explanation of the different degree of the OZI rule violation in different channels of $\bar{p}p$ annihilation can be obtained under hypothesis of polarized strangeness in the nucleon [31].

Indeed, the results from the deep inelastic lepton-nucleon experiments indicate that strange quarks and antiquarks in the nucleon have a net polarization opposite to the proton spin [32]:

$$\Delta s \equiv \int_0^1 dx[q_\uparrow(x) - q_\downarrow(x) + \bar{q}_\uparrow(x) - \bar{q}_\downarrow(x)] = -0.10 \pm 0.03. \qquad (17)$$

It is impossible to borrow directly this result from the deep inelastic region for the consideration of ϕ production at small momentum transfers. This polarization may decrease with decreasing momentum transfer (see, for instance [33])

However there are well-motivated expectations that within the chiral quark model it is possible to connect the significant strange content in the proton, negative sign of the strange quark polarization and recently observed $\bar{u}$-$\bar{d}$ asymmetry in the nucleon[34].

So let us perceive the message from the deep inelastic region as a prompt and consider what happens if the nucleon wave function, even at small momentum transfers, contains an admixture of the $\bar{s}s$ pair with spins of both strange quarks oriented against the nucleon spin.

Let us consider $\bar{p}p$ annihilation from a spin–triplet initial state, in which the $\bar{p}$ and p spins are parallel (see, Fig.4).

In this case $\bar{s}$ and s quarks in both nucleons will also have parallel spins. If the rearrangement diagram of Fig.4 is dominant and polarization of strange quarks is not changed during the annihilation, then the $\bar{s}$ and s quarks in the final state will have parallel spins, as in the quark model wave function of the ϕ meson. If the $\bar{p}p$ initial state is an S–wave, the $\bar{s}s$ pair will probably also be in an S–wave as in the ϕ meson. Therefore, the maximum enhancement of ϕ production is expected in the $^3S_1$ channel, as

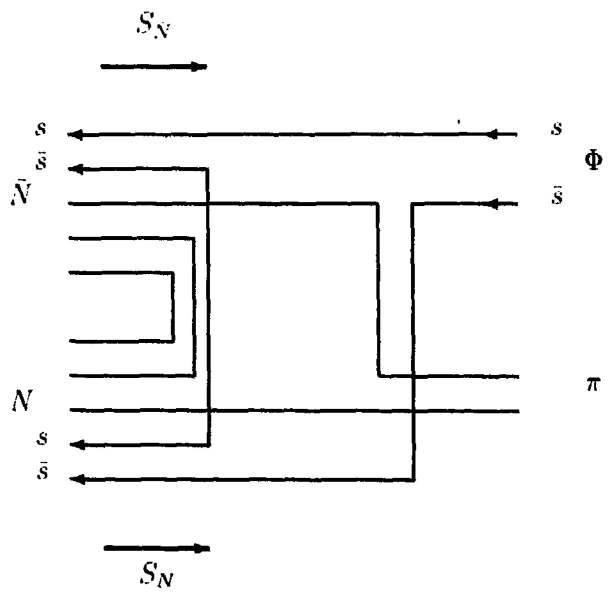

Figure 4: Annihilation of $\bar{N}N \rightarrow \phi\pi$ from the spin triplet state. The arrows show the direction of nucleons and strange quark spins.

observed in the $\phi\pi$ final state. This model predicts weaker enhancements in the $^1S_0$ channel, as observed.

This model also suggests qualitatively why ϕ production may be enhanced more in $\bar{p}p$ annnihilation at rest than in other hadronic interactions. The reason is that higher–energy collisions involve an increasing mixture of partial waves, implying that the S–wave state "rearrangement" that favours ϕ production becomes progressively more diluted. On the contrary, in the $\bar{p}p$ annihilation at rest only one pure spin state $^3S_1$ is possible for $\phi\pi$ production in S–wave annihilation. To reproduce this situation, for instance in proton-proton interaction, one should collide a 100% polarized beam with a 100 % polarized target.

The model predicts that the large enhancement of $\bar{N}N \rightarrow \phi\pi$ diminishes as the energy increases. This completely agrees with the results of Crystal Barrel [16] on annihilation in flight. They found that the production rate of $\phi\pi$ at 600 MeV/c is smaller about 5 times than that at rest. Indeed, at 600 MeV/c the S-wave is about 14-20% of the annihilation cross section [17].

However, in spite of the polarization model explain the salient features of the data on ϕ production, it is rather idealized. For instance, the polarizations could be altered during the annihilation process, it is not clear in advance that the rearrangement diagram of Fig.4 is dominant. The validity of these and other approximations should be verified experimentally. The model has a number of rather concrete predictions. It is challenging to test them owing to the large impact on our understanding of the nucleon structure.

4 Tests of the ϕ production dynamics

The possible tests of the polarized strangeness model comprise the checks of the spin dependence of the OZI-violating amplitudes, their energy and momentum transfer dependence.

- Spin dependence.
  - Strong dependence of the ϕ yield on the quantum numbers of the initial state is a very distinctive feature of antiproton annihilation. However this phenomenon needs further experimental confirmation. The ASTERIX collaboration has not enough statistics with LX-trigger to see the signal from ϕ, their estimation was 4±4 events of $\phi\pi$ which leads to the production rate from P-wave $B.R.(\bar{p}p \to \phi\pi^0) = (0.0 \pm 0.3) \cdot 10^{-4}$.
    It is important to verify experimentally if this dependence of ϕ production from the initial state really exists.
    Now the OBELIX collaboration has acquired significant statistics on antiproton annihilation into charged kaons under different conditions. Thus the channel

$$\bar{p} + p \to K^+ + K^- + \pi^0 \tag{18}$$

has been studied for the antiproton annihilation in a gas hydrogen target at NTP and for the low pressure of 5 mbar. At such low pressure the antiproton annihilation takes place mainly from P-wave states. Preliminary results confirm the ASTERIX ones but with significantly higher statistics.

- The arguments for $\phi\pi$ enhancement in production from the $^3S_1$ initial state can be extended to other $\bar{s}s$ resonances, in particular to production of the $f_2'(1525)$ compared to the $f_2(1270)$. Using the quadratic mass formula one may obtain

$$R' = f_2'(1525)/f_2(1270) = 16 \cdot 10^{-3} \qquad (19)$$

before applying phase space corrections.
The $f_2'(1525)$ was not seen by bubble chamber experiments in annihilations at rest [35], which gave an upper limit of $3.8 \cdot 10^{-3}$ on $\bar{p}p \to \pi^0 f_2'$.
Since the f_2' is a spin–triplet P–wave state in the quark model, the type of argument used to motivate enhancement of ϕ production in $^3S_1$ state would favour a large f_2'/f_2 ratio in $^3P_1$ states. It is interesting to note that the f_2 yield in P-wave annihilation is known [36] to be five times greater than in the S-wave: $Y^P_{f_2} = 1.85 \pm 0.24\%$. If the above prediction of enhanced f_2' production is correct, and the effect is as large as in the $^3S_1$ ϕ production case, the signal for f_2' production in P–wave annihilation should be clearly visible, with the branching ratio of $\bar{p}p \to \pi^0 f_2'$ possibly as large as 0.1-0.2%.
- The largest violation of the OZI rule occurs in the $\phi\gamma$ channel (see Table 1). This channel was measured for antiproton annihilation in liquid, where the S-wave annihilation is dominant. The $\phi\gamma$ final state is possible either from spin singlet $^1S_0$ or from spin triplet $^3P_{0,1,2}$ states. So if the ϕ production is really enhanced for spin triplet states, then one would expect that the ratio $\phi\gamma/\omega\gamma$ will increase for annihilation in gas hydrogen target at NTP or at low pressure, where the P-wave annihilation is dominant.
- An interesting possibility of testing the model is provided by the $\phi\pi\pi$ final state where, contrary to the binary channels of ϕ production, the annihilation from the same partial wave is possible both from the spin-triplet and spin-singlet states. Spin-parity analysis of the Dalitz plot of the $\bar{p}p \to \phi\pi\pi$ annihilation should demonstrate the dominance of the $^3S_1$ initial state.
- It is important to check the spin dependence of the OZI violating $\bar{p}p \to \phi\phi$ amplitude. The inrinsic strangeness model pre-

dicts that even larger violation can be seen in the experiment with a polarized beam and target when the initial spin-triplet state is prepared. In the spin-singlet state the OZI violation should be less pronounced.

– It is interesting to study the spin structure of the OZI-allowed process

$$p + p \to K^* + K^* \tag{20}$$

If the intrinsic strangeness also manifests itself in the OZI-allowed processes, spin correlations should appear in the final state. For example, when the initial $\bar{p}p$ pair is in the spin-triplet state, the final $K^*\bar{K}^*$ channel should be dominated by the $S = 2$ state.

- Energy dependence.
  - The intrinsic strangeness model predicts that the $\phi\pi/\omega\pi$ ratio measured in the annihilation in flight will fall down, following the decreasing admixture of the $^3S_1$ state. Recent preliminary results from the Crystal Barrel experiment [16] indicate that the production rate of the $\phi\pi^0$ channel decreases by approximately 5-fold when the momentum of the antiproton increases to 600 MeV/c. This measurement should be complemented by determination of the $\omega\pi$ energy dependence.
- Dependence on the momentum transfer.
  - It is interesting to verify if there is a difference in the momentum transfer dependence of ϕ and ω production. For this purpose it is suitable to measure the $\phi\pi\pi$ and $\omega\pi\pi$ reactions for annihilation at rest or to compare $\phi\pi$ and $\omega\pi$ differential cross sections for annihilation in flight. Such a difference was already noted [37] in a bubble chamber experiment on $\bar{p}p \to \phi\pi\pi$ and $\omega\pi\pi$, however with low statistics.
  - The largest momentum transfer in the ϕ production by stopped antiproton annihilation is available in the so-called Pontecorvo reaction

$$\bar{p} + d \to \phi + n \tag{21}$$

We therefore may expect an even higher ϕ/ω ratio in the reactions of this type.

Several other tests are possible outside antiproton annihilation.

The idea that the $\bar{s}s$ in the proton are polarized has interesting implications for reactions with polarized protons, such as

$$\vec{p} + \vec{p} \longrightarrow p + p + \phi \qquad (22)$$

If the idea is correct, ϕ meson production in this reaction should be maximal when the beam and the target nucleons have parallel polarizations, and minimal when they are antiparallel. Another interesting reaction is

$$\vec{p} + \vec{d} \longrightarrow \text{He} + \phi \qquad (23)$$

Here again ϕ production should be maximal if the initial-state p and d have parallel polarizations.

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Сапожников М.Г. E15-94-501

Образование ϕ-мезонов в $\overline{N}N$-аннигиляции

Недавние эксперименты по рождению ϕ-мезонов в аннигиляции покоящихся антипротонов показали значительное (на фактор 30-50) нарушение правила ОЦИ. Обсуждаются экспериментальные данные по рождению ϕ-мезонов, а также возможные теоретические объяснения сильного нарушения правила ОЦИ.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

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Production of ϕ-Mesons in $\overline{N}N$-Annihilation

Recent results from the experiments on the ϕ-meson production in the annihilation of stopped antiprotons have demonstrated a significant (by a factor of 30-50) violation of the OZI rule. Experimental information on the ϕ-meson production is discussed and possible theoretical explanations of the strong OZI rule violation are reviewed.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

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