The Centauro events as a result of induced pions emission

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Preface

Like in the laser beam, where the Bose-Einstein statistics of photons results in its high momentum coherence, in the production of large number of pions this statistics may lead to strongly enhanced emission of pions with the same charge. Because of that, in production of a hundred pions, the events without neutral pions or, on the contrary, without the charged ones, extremely rare from point of view of classical statistics, obtain appreciable probability and can be observed. They were observed in the cosmic rays experiments (Centauro events) at energy $\sim 1000 \text{ TeV}$. This energy region will be covered and studied in detail in the LHC experiments.

The consequences of the Bose-Einstein statistics for pion creation and their charge distributions is being discussed in the literature for a rather long period of time (see, e.g., the paper [I] in the list below). A possibility of formation of a large domain of disoriented chiral condensate was indicated in the work [II] and then in [III,IV]. The more detailed lists of references devoted to this subject can be found in the more recent publications, see, e.g., the papers [V,VI,VI].

As far as we aware, our paper [a] was one of the first where the pion charge distributions were calculated, proceeding directly from the Bose-Einstein statistics, and where the analogy with the induced photon emission was strongly emphasized. However because of some technical reasons this paper was never sent to any physical journal. Its short version was published in [b] (in Russian) and is practically inavailable. Therefore we put now the paper [a] in the LANL archive. No changes have been done in this text except for correcting some misprints.

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Abstract

It is shown that only in the case of $n$ pion production amplitude (at $n > 10$), which is symmetric enough relative to the momenta permutations, there is appreciable probability of events with nothing but charged or nothing but neutral pions. Significant enhancement of the probability of these events in comparison with that follows from Poisson distribution is caused by induced pions emission, in complete analogy with the phenomenon of the induced photon emission in QED.

1 Introduction

Overwhelming majority of theoretical pictures describing the high energy processes at high multiplicity leads to Poisson distribution for probability of emission a given number of pions, provided the average number of pions is fixed. In more sophisticated models this probability is given by the sum of Poisson distributions - see papers [1] and references therein. In all the distributions of that kind the average number of neutral $n_0$ and charged pions $n_{ch}$ are determined by the following relations:

$$n_0 = \frac{1}{3} \bar{n}, \quad n_{ch} = \frac{2}{3} \bar{n}.$$ 

Notice that the experimanteal data obtained by the existing accelerators ($\sqrt{s} \leq 540$ GeV) do agree with that theoretical distributions. On the other hand, in cosmic rays the events were found with large multiplicity ($\bar{n} \sim 10 \div 100$), in which the neutral pions are absent [2, 3]. Their energy is about $E_{lab} \sim (1 \div 2)10^3$ TeV. These events were called Centauros. Below we shall suppose that charged particles in Centauro events are the pions.

Notice that it is practically impossible to interpret Centauro events as a fluctuations of Poisson distribution - the probability $w(\pi^+\pi^-)$ for such a fluctuation is too small. For example, for $\bar{n} = 100$ we get:

$$w(\pi^+\pi^-) = e^{-n_0} \approx 10^{-14}.$$ 

As it will be shown below, the charge distribution in a system of the given total number of pions $n$ is closely connected with symmetry properties of the production amplitude $M(p_1, \tau_1, \ldots, p_n, \tau_n)$ relative to permutations of isotopic indices $\tau_1, \ldots, \tau_n$. The later symmetry leads also to certain type of symmetry for the permutations of momenta $p_1, \ldots, p_n$, as it follows from Bose-properties for whole amplitude $M$. Notice that the charge distribution differs from Poisson one if amplitude $M$ is symmetric relative to permutation of momenta. As it will be seen below, we get in this case the significant increase of the probability of events with neither neutral nor charged pions. On the other hand, the permutation properties of amplitude $M$ can give very useful information on properties of the objects generating the Centauro events.

For a system of $n$ pions with small values of total isospin the charge distributions for certain types of symmetries (Young tableaux) were derived more that twenty years ago by Pais [4]. The charge distribution in the case, when all possible Young tableaux give the same contribution to the wave function, was obtained in [6]. In this case the distribution has sharp form and is close to Poisson one for large values of $n$.

\footnote{In ref. [4] concrete realizations for all Young tableaux with one and two rows were constructed, some special cases with three lines were considered also. In connection with this question see also paper [5].}
Recently in connection with Centauro events in ref. [7] the role of small isospins in a system of \( n \) pions was emphasized. This is an important fact because in the nuclear collisions namely small values of isospin are realized. To explain Centauro events in ref. [7] the most symmetric form of wave function for a system of \( n \) pions was also used. These two assumptions automatically lead to the smooth charge distribution, in accordance with ref. [4].

In the present paper we are going to collect altogether those results of refs. [4, 6, 7], which in our opinion may take immediate attitude toward Centauro problem. Transparent deduction of the results [4, 6, 7] will be given. Taken altogether, these results give rigid restrictions on theoretical models of Centauros. We consider this paper as a short review.

Physical reasons will be explained, which enhance the production probability of the pions of the same sort. This enhancement takes place when the totally symmetric (in momentum space) amplitude dominates, and it compensates Poisson’s diminition of process. *This phenomenon has much in common with induced photon emission, that leads to formation of laser bunch.*

### 2 Connection between the symmetry of amplitude and the charge distribution of pions

The production amplitude of \( n \) pions has the form:

\[
M(p_1, \tau_1; p_2, \tau_2; \ldots; p_n, \tau_n) = \sum_{\alpha} M_{\alpha}(p_1, \ldots, p_n) \varphi_{\alpha}(\tau_1, \ldots, \tau_n), \tag{1}
\]

where the sum is taken over all the possible types of symmetry \( \alpha \), characterized by Young tableaux. As we have only three sorts of pions \((\pi^+, \pi^0, \pi^-)\), index \( \tau_i \) \((i = 1, 2, \ldots, n)\) takes also only three nonzero values. It follows that the rows number in Young tableaux doesn’t exceed three as well. Totally symmetric function \( \varphi_{\alpha}(\tau_1, \ldots, \tau_n) \) corresponds to the only Young tableau with one row.

The most important fact consists in the following: more symmetric function \( \varphi_{\alpha}(\tau_1, \ldots, \tau_n) \) gives more smooth distribution in charge space. On the contrary, less symmetric Young tableaux with three rows give sharp charge distribution. Notice that the total number of young tableaux is very large:

\[
N \approx \frac{3}{8} \sqrt{\frac{3}{\pi}} \frac{3^n}{n^{3/2}}
\]

and most part of \( N \) comes from Young tableaux with three rows. So to observe the Centauro events with appreciable probability, it is necessary to increase the role of symmetric terms (with one and two rows) in the sum (1). In other words, it means that by some dynamical reasons the pions are produced in symmetric states in momentum space.

First of all, let us demonstrate the pion distribution in the case when large number of amplitudes with the different symmetry types gives the same contribution into the sum (1). Consider the case of even number \( n = 2k \) with total zero isospin \( I = 0 \). We shall obtain the pions distribution for the amplitude in a special form:

\[
M = \hat{S}\{M(p_1, p_2, \ldots, p_n)(\vec{a}_1 \cdot \vec{a}_2) \ldots(\vec{a}_{2k-1} \cdot \vec{a}_{2k})\}, \tag{2}
\]
where $\vec{a}_i$ ($i = 1, \ldots, n$) is isotopic vector of pion, $\hat{S}$ is the symmetrization operator. Equation (2) for $M$ is the special form of (4), as eq. (2) is symmetric relative to permutations of pions in pairs, e.g., $\vec{a}_1 \leftrightarrow \vec{a}_2$, etc. Nevertheless this form of $M$ gives rather sharp distribution in number of neutral or charged pions. Suppose that $M(p_1, p_2, \ldots, p_n)$ depends sharply on the arguments $p_1, p_2, \ldots, p_n$ so as it differs noticeably from zero only when $p_1 \approx \bar{p}_1, p_2 \approx \bar{p}_2, \ldots$, \(\bar{p}_1 \neq \bar{p}_2 \neq \bar{p}_3 \neq \ldots \bar{p}_n\). This condition provides that the amplitude $M$, eq. (2), contains a large number of terms with different permutation symmetries. Making symmetrization, we get $M(p_2, p_1, p_3, \ldots, p_n) \approx 0$ for $p_1 \approx \bar{p}_1, p_2 \approx \bar{p}_2$. On the contrary, $M(p_2, p_1, p_3, \ldots, p_n)$ differs from zero when $p_1 \approx \bar{p}_2, p_2 \approx \bar{p}_1, p_3 \approx \bar{p}_3, \ldots$. We get the same result making permutation of any pair of arguments. So, integrating over whole phase volume to calculate the cross section, we obtain that all the permuted terms in eq. (2) give the same contribution. It follows that the value of cross section is proportional to a number of nonzero isospin amplitudes in eq. (2).

Now let us find out how this number depends on the number of charged (or neutral) pions. Assume that among $n = 2k$ pions there are $k_1$ of $\pi^+, k_1$ of $\pi^-$ and $2k_2$ of $\pi^0$-mesons. Considering vectors $\vec{a}_i$ in (2) in the coordinates $a_\pm, a_0$, we get for the isospin part of amplitude:

$$\chi = \left[\delta_{\tau_1}^{\tau_1'} \cdots \delta_{\tau_{k_1}}^{\tau_{k_1}'}\right] \left[\delta_{\sigma_1}^{\sigma_1'} \delta_{\sigma_2}^{\sigma_2'} \cdots \delta_{\sigma_{k_2}}^{\sigma_{k_2}'}\right].$$

(3)

As it is seen, $\chi = 1$ for $\tau_1 = \ldots = \tau_{k_1} = 1, \tau_1' = \ldots = \tau_{k_1}' = -1, \sigma_1 = \ldots = \sigma_{k_2} = \ldots = \sigma_{k_2}' = 0$. Let’s look for such permutations of mesons, which give us nonzero values of $\chi$. First we can do all the possible permutations of upper indices in the first brackets in (3), the set of lower indices being fixed, and obtain the factor $k_1!$. Secondly it is also possible to permute indices in second bracket in eq. (3). This operation changes positions of $\pi^0$-mesons (no identical operations have been done!). The number of nonzero amplitudes is $(2k_2 - 1)!!$. Permutations of indices between both brackets give zero result. From this it follows that the probability $w(k_1, k_2)$ to emit $k_1$ pairs of $\pi^+\pi^-$ and $k_2$ pairs of $\pi^0$ is

$$w(k_1, k_2) \sim \frac{k_1! (2k_2 - 1)!!}{(k_1!)^2 (k_2!)^2}.$$  

(4)

The denominator in (4) appeared from the usual normalization condition for the cross section with an identical particles in final state, see, for instance, ref. [8]. Calculating the normalization constant for $w(k_1, k_2)$, we finally get:

$$w(k_1, k_2) = \frac{k!}{k_1! k_2!} \left(\frac{2}{3}\right)^{k_1} \left(\frac{1}{3}\right)^{k_2},$$

(5)

where $k = k_1 + k_2$. This is binomial distribution. For large values of $k$ and small $k_1$ (or $k_2$) we may approximate eq. (3) by Poisson distribution. It follows from eq. (3) that the emission probability of nothing but charged particles only (i.e., the probability to observe the Centauro event) is suppressed strongly, e.g., $w(\pi^+\pi^-) \approx 10^{-9}$ for $n = 100$.

In the deduction given above we used for amplitude $M$ partially symmetric form, eq. (2). Surely there exist other combinations of isovectors $\vec{a}_i$ of less symmetric form, e.g. $\vec{a}_1 \cdot [\vec{a}_2 \times \vec{a}_3]$.

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$^2$Total number of terms in (3) and in the cross section also is $2^k k! k_1! (2k_2 - 1)!!$. Later on we shall study the distribution over $k_1$ and $k_2$ only.
Being included in $M$, they would give more sharp charge distribution than it follows from (5). In the most consistent form terms of all different symmetries were taken into consideration in ref. [6]. Contribution to the cross section from all those terms was taken to be equal. In comparison with (5) the asymptotics of formula (16) from ref. [6] gives the probability of event without charged pions

$$w(\pi^0) = \frac{8}{3} \sqrt[3]{n} \sqrt[3]{\pi^3}$$  \hspace{1cm} (6a)$$

Analogously obtained probability of nothing but charged particles has the form:

$$w(\pi^+\pi^-) = \frac{8}{3} \sqrt[3]{2} \left(\frac{2}{3}\right)^n$$  \hspace{1cm} (6b)$$

This is less than it follows from eq. (5) at $n = 2k$.

Let us consider now the contrary case. We find the charge distribution in a system of $n = 2k$ pions at $I = 0$, described by the state totally symmetric in the momenta (and isospin) variables. Corresponding isospin wave function is obtained from eq. (2) provided the amplitude $M(p_1, \ldots, p_n)$ is not changed under the momenta permutations. We emphasize that in this case the amplitude (2) is not yet the amplitude of a particular form. In this case it is defined unambiguously and doesn’t depend on the angular momentum addition scheme in the initial amplitude which produces after symmetrization the amplitude eq. (4). Therefore all nonzero terms in eq. (2) are the same, that results in 100% constructive interference. Then instead of eq. (4) we obtain

$$w(k_1, k_2) \sim \frac{(k_1!)^2 [(2k_2 - 1)!!]^2}{(k_1!)^2 (2k_2)!}.$$  \hspace{1cm} (7)$$

Calculating the normalization factor by means of the relation:

$$\sum_{l=0}^{k} \frac{(2l - 1)!!}{(2l)!!} = \frac{(2k + 1)!!}{(2k)!!},$$

where, by definition, $(-1)!! = 1$, we find:

$$w(k_1, k_2) = \frac{2^kk!}{(2k + 1)!!} \frac{(2k_2 - 1)!!}{2^{k_2}k_2!}.$$  \hspace{1cm} (8)$$

In contrast to eq. (3), the distribution (8) is rather smooth. It is shown in figure 1. At $k_2 \gg 1$ we have $w(k_2) \sim 1/\sqrt{k_2}$. The average numbers of the neutral and charged pions both in the case of distribution (8) and in the case of eq. (4) are found the same and equal to

$$n_0 = \frac{1}{3}n, \quad n_{ch} = \frac{2}{3}n.$$  

From eq. (7) at $n \gg 1$ we obtain the production probabilities of nothing but neutral pions $w(\pi^0)$ or nothing but charged pions $w(\pi^+\pi^-)$ (Centauros):

$$w(\pi^0) = \frac{1}{n}, \quad w(\pi^+\pi^-) = \sqrt{\frac{\pi}{2n}}.$$  \hspace{1cm} (9)$$
Figure 1: The function \( y(m) = (2m - 1)!! / (2^m m!) \). It gives multiplicity distribution over a number of paires of neutral pions.

These probabilities are enhanced by many orders in comparison to eq. (3). This enhancement is just well known in quantum optics the induced emission phenomen. The numerator of eq. (4) contains extra (in comparison with eq. (2)) factorials \( k_1! (2k_2 - 1)!! \). These extra factorials appear due to interference, which is extremely essential in the case of symmetric state relative to the final pion momenta permutations. The same behaviour of amplitude is found in the case of pion emission with the same momenta. The reason of this enhancement results from the fact that the emission of one sort bosons in the state with the same momenta has essential advantage over the emission of the same number of bosons of two or several sorts. Note that according to eq. (5) the probability \( w(\pi^0) \) by \( (\pi n/2)^{1/2} \) times less than \( w(\pi^+\pi^-) \), in contrast to the Poisson distribution. In the latter case we have:

\[
w(\pi^0) \ll w(\pi^+\pi^-).
\]

However, inspite of maximal enhancement of neutral pion production probability \( w(\pi^0) \), it remains less than \( w(\pi^+\pi^-) \). This fact is connected with particular diminution of "initial" Poisson probability \( w(\pi^0) \).

This can be also explained without starting from the Poisson distribution. Although the enhancement of induced \( \pi^0 \)-emission is considerably stronger than that in the case of the same number of \( \pi^+\pi^- \) (see below eq. (9)), however the combinatorial factor (the coefficient 2) enhances the \( \pi^+\pi^- \)-production (see below eq. (10)). This factor appears in expansion of the scalar operator \( \vec{c}^{\dagger 2} = 2c_{\pi^+}^{\dagger}c_{\pi^-}^{\dagger} + c_{\pi^0}^{\dagger 2} \) in terms of the pion creation operators.
In order to emphasize more clearly the connection between possible Centauro production and the induced photon emission we reproduce eq. (8) by means of the second quantization formalism. The totally symmetric isospin \( n \)-particle wave function at \( I = 0 \) has the form:

\[
|\phi\rangle = \frac{1}{\sqrt{(2k + 1)!}} \left( \bar{c}^{12} \right)^k |0\rangle,
\]

where \( \bar{c}^{12} = 2c_{\pi^+}^\dag c_{\pi^-}^\dag + c_{\pi^0}^2 \), \( c_i^\dag \) is the pion creation operator of \( i \)-th sort, \( n = 2k \). Calculating the amplitude \( \langle k_1\pi^+, k_1\pi^-, 2k_2\pi^0 | \phi \rangle \) and taking into account that

\[
\langle k_1\pi^+ | (c_{\pi^+}^\dag)^k_1 | 0 \rangle = \sqrt{k_1!}, \quad \langle 2k_2\pi^0 | (c_{\pi^0}^\dag)^{2k_2} | 0 \rangle = \sqrt{(2k_2)!},
\]

we find:

\[
\langle k_1\pi^+, k_1\pi^-, 2k_2\pi^0 | \phi \rangle = C_{k_1}^{k_2} \frac{k_1! \sqrt{(2k_2)!}}{\sqrt{(2k + 1)!}},
\]

where \( C_{k_1}^{k_2} \) is the binomial coefficient. The amplitude squared reproduces eq. (8). Enhancement of the pion production amplitude in the case of the same sort of pions is due to the same factors (10) which enhance the photon induced emission amplitude.

Note that the formulae (9) for \( w(\pi^0) \) and \( w(\pi^+\pi^-) \) coincide with the result obtained in ref. [7] with accuracy of replacement of the pion number \( n \) in eq. (9) by the average number \( \bar{n} \) in ref. [4]. The probability of a given number of pions in ref. [4] was described by the Poisson distribution. Averaging eqs. (9) by Poisson distribution just leads to the replacement of \( n \) by \( \bar{n} \) (with accuracy of the power corrections).

3 Role of the small total isospin of the \( n \) pion system

It was shown in the previous section that refusal from domination of most symmetric isospin wave function leads to negligibly small probability of Centauro production. In the present section we show that refusal from small isospin values also sharply diminishes the probabilities \( w(\pi^0) \) and \( w(\pi^+\pi^-) \) even in the case of totally symmetric wave function. This aspect of phenomenon has been emphasized in ref. [4].

Let us calculate the probabilities \( w(\pi^0) \) and \( w(\pi^+\pi^-) \) considering the totally symmetric \( n \)-pion state with \( n = 2k \) and isospin \( I = n, I_3 = 0 \). The isospin wave function has the form:

\[
|\phi_I\rangle = A(I) \left( \bar{c}^{12} \right)^k Y_0 \left( \frac{\bar{c}^\dag}{\sqrt{\bar{c}^{12}}} \right) |0\rangle,
\]

where \( A(I) \) is the normalization factor:

\[
A(I) = \sqrt{\frac{4\pi}{(2I + 1)!!}}.
\]

In ref. [7] the probabilities \( w(\pi^0) \) and \( w(\pi^+\pi^-) \) were calculated by projecting pion field on the state of small isospin, \( I = 0, 1 \).

4 The charge structure of the state with \( I_3 \) close to the maximal value is almost definite. Therefore the problem appears for the state with small \( I_3 \) only.
The probabilities concerned are determined by the following amplitudes:

\[ M(\pi^0) = \langle 2k\pi^0|\phi_I \rangle = A(I) \sqrt{\frac{2I+1}{4\pi}} P_I(1) \langle 2k\pi^0|(c^\dagger_{\pi^0})^{2k}|0\rangle, \]

\[ M(\pi^+\pi^-) = \langle k\pi^+, k\pi^-|\phi_I \rangle = A(I) \sqrt{\frac{2I+1}{4\pi}} P_I(0) 2^k \langle k\pi^+, k\pi^-|(c^\dagger_{\pi^0}c^\dagger_{\pi^-})^k|0\rangle, \]

where \( P_I(x) \) is the Legendre polynom.

\[ \text{From here at } I \gg 1 \text{ we obtain:} \]

\[ w(\pi^0) = \frac{\sqrt{\pi I}}{2^I}, \quad (13a) \]

\[ w(\pi^+\pi^-) = \frac{\sqrt{2}}{2^I}. \quad (13b) \]

At \( I = n \approx 100 \) the probabilities (13a), (13b) have the order of \( 10^{-30} \).

4 Conclusion

Thus we have convinced that the events containing nothing but \( \pi^+\pi^- \)-mesons or \( \pi^0 \)-mesons at high multiplicity can have appreciable probability only at simultaneous realization of the following two conditions:

1. Symmetric state of \( n \)-meson system relative to the permutation of momenta (and isospin indices).

2. Small total isospin.

The first condition seems us to be considerably more essential than the second one, since due to isospin conservation the second condition is satisfied automatically, while the first condition implies the strong restrictions to the dynamics of high multiplicity pion production. We emphasize that these results follow from rather general consideration. Therefore any model, which pretends to explanation of Centauros, must first of all satisfy to two these conditions.

It should mention that under symmetric function we mean the function corresponding to the Young tableau with one or two rows. Thus, proceeding from ref. [4] one can obtain that \( I = 0 \) for the Young tableau with two equal rows \( w(\pi^+\pi^-) = 1/n \), but \( w(\pi^0) = 0 \). However, the Young tableau with three approximately equal rows leads to distribution which differs from zero only at \( n_0 \) and \( n_{ch} \), close to \( \frac{1}{3}n \) and \( \frac{2}{3}n \) correspondingly. Since the overwhelming majority of the Young tableaux is the Young tableaux with three rows, namely they determine the distribution when all the Young tableaux give equal contributions.

On these grounds it can be conceived that Centauros are produced from decay of a particle as if consisting from large number of pions in totally symmetric state. On the ground that the experimental hadron transverse momenta in Centauro equal to \( p_T \geq 1.5 \text{ GeV/c} \), one can expect that the size of this hypothetical object is of the order of \( (1.5 \text{ GeV/c})^{-1} \). The field with energy \( E \approx 230 \text{ GeV} \) [3] is concentrated in this volume. Considering the pions as quanta of this field...

\[ ^5 \text{We mean the models in which the hadrons produced are considered as pions.} \]
one can suppose that this object could be similar in its properties to the classical solution of a field equation. One can expect that namely at high energy the heavy particles having the properties close to the classical solutions can be produced. This hypothesis have been suggested in ref. [9]. Note that possible soliton solution to explain Centauros is, for example, the slowly damping classical solution for Higgs scalar field found in ref. [10].

Let us give a possible estimation of the Centauro production cross section. Assuming that a Centauro is produced from a soliton decay, we see that the only dimensional parameter is its size $r_0 \sim (1.5 \text{ GeV}/c)^{-1}$. It follows that relative probability of the soliton production is the ratio:

$$w \sim r_0^2 / r_{st}^2 \sim 10^{-2},$$

where $r_{st}$ is the strong interaction radius. This estimation is rather rough. The probability of Centauro production is obtained by multiplying eq. (14) by (9). Therefore the probability to find a Centauro is estimated as

$$w(\text{Centauro}) \sim 10^{-3}. \quad (15)$$

Although this estimation does not depend explicitly on energy, it becomes valid only beginning from rather high energy (which we don’t estimate), when quasiclassical objects can be produced. CERN SPS-collider experiments [11, 12] at $\sqrt{s} = 540$ GeV give so far no evidences for Centauro production. From the present point of view this means that inspire the fact that the energy $\sqrt{s} = 540$ GeV exceeds the threshold for production of the mass $M = 230$ GeV/c$^2$, this energy is not enough for proceeding the physical phenomena leading to Centauro production (e.g., for developing the soliton object).

The other approaches to Centauros were discussed in refs. [3, 13].

5 Appendix

From the present consideration some conclusions follow for the high multiplicity pion production in nuclear reactions. It follows that charge distribution of pions produced in any nuclear reaction would be smooth provided the pion momenta are close enough to each other. The latter comes true in kinematics near the phase volume bound. For example, in the reaction

$$pp \rightarrow pp + n\pi \quad (16)$$

at highest possible pion number $n$ allowed by energy conservation the reaction kinematics automatically forbids the wide variation of the pion momenta. This ensures automatically the total symmetry of pion production amplitude relative to the momenta permutation in the narrow allowed region. As it was shown above, we obtain the smooth charge distribution in this case.

It would be useful to carry out the experimental research of the reaction (16) in the kinematics concerned. Such investigation is possible at the meson factory accelerators, where due to high intensity the small cross sections can be measured.

Another interesting reaction is the extremely many pion annihilation of low energy antiprotons (see ref. [14]):

$$p + \bar{p} \rightarrow n\pi. \quad (17)$$
Usually rather sharp binomial distribution (as eq. (5)) is expected in such processes, which follows from the statistical models \[15\]. In this reaction at highest possible multiplicity \(n\) we expect a smooth distribution as well.

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