A proton-pentaquark mixing and the intrinsic charm model

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A new interpretation of intrinsic charm phenomenon based on the assumption of pentaquark $|uudc\bar{c}\rangle$ mixing with a proton is offered. The structure function of the $c$-quark in the pentaquark is constructed. Mixing different states is considered theoretically and using experiment data on $D$-meson production and inclusive production of the hidden charm particles.

Today there are many articles \cite{1,2} related to intrinsic charm concept, which was introduced by Brodsky et al. \cite{3}. In the present article we want to discuss a new interpretation of this phenomenon. As will be shown below, the intrinsic charm problem is closely related to the pentaquark $|uudc\bar{c}\rangle$ existence and mixing of that state with the proton.

Authors of ref. \cite{3} made the assumption that Fock state decomposition of the proton wave-function contains a non-negligible $|uudc\bar{c}\rangle$ component, which results in the specific distribution of $c$-quark in proton. According to \cite{3}, the probability to find $|uudc\bar{c}\rangle$ configuration, in classical perturbation theory, is given by the expression

$$W(A \to q_1 \ldots q_5) \sim \left| \frac{\langle q_1 \ldots q_5 | M | A \rangle}{E_A - E_{q_1} - \ldots - E_{q_5}} \right|^2,$$

where $q_i$ is the momentum of $i$-th quark, $A$ is an initial state, $M$ is a transition matrix element, $E_i$ is the energy of $i$-th quark.

Transforming the above expression and integrating over all quark’s contributions except of one $c$-quark, the authors of \cite{3}, derive the expression the distribution of $c$-quark:

$$P(x) = N x^2 \left[ (1 - x)(1 + 10x + x^2) + 6x(1 + x) \ln \frac{1}{x} \right],$$

where $N$ is determined by normalization condition for one c-quark $\int P(x)dx = 1$.

The distribution $P(x)$ is shown in fig. 1 by solid line. From eq.(2) and Fig.1 we can see that average momentum fraction of $c$-quark is equal to $2/7$. As a result, noticeable

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contribution of intrinsic charm into inclusive production of $D$, $J/\psi$ or $\chi_c$-mesons should be seen at $\langle x \rangle \approx 2/7$ [4, 5].

It is necessary to notice that the probability to find $|uud\bar{c}\rangle$ configuration [1] was constructed under inherently perturbative assumption, since the factor $1/(E - E')$ is used. Let us consider alternative, essentially nonperturbative, model [6]. We construct structure function for $c$-quark in the pentaquark $|uud\bar{c}\rangle$, which has quantum numbers like a proton. The probability to find $i$-th quark with momentum fraction $x_i$ in proton for small $x_i$ can be obtained from Regge asymptotic:

$$dP_i(x_i) \sim \frac{x_i^{1-\alpha_i}}{\sqrt{x_i^2 + \mu^2/P^2}},$$

(3)

where $\alpha_i$ is the intercept of corresponding leading Regge trajectory. For sea quarks this parameter is equal to 1, in the case of light valence quarks we have $\alpha_{1,2,3} = \alpha_{u,d}(0) \approx 0.5$ from leading Regge $f, A_2$ trajectories, while for $c$-quark the intercept of leading $J/\psi$-trajectory is equal to $\alpha_{4,5} = \alpha_c(0) \approx -2.2$ [7, 8]. Thus, the structure function of the $n$-particle state has the form

$$dG(x_1, \ldots, x_n) \sim \delta \left(1 - \sum_{i=1}^{n} x_i\right) \prod_{i=1}^{n} \frac{dx_i x_i^{1-\alpha_i}}{\sqrt{x_i^2 + \mu^2/P^2}}.$$

(4)

Integrating this expression in the case of $|uud\bar{c}\rangle$ pentaquark over $dx_1 \ldots dx_3$ we can calculate the structure function of $c$-quark:

$$G(x) = M x^{-\alpha_5} (1 - x)^{-1+\gamma_A+\sum_{i=1}^{4}(1-\alpha_i)},$$

(5)

where $M$ is a parameter, which stands normalization: $\int G(x) dx = 1$.

In original Kuti-Weisskopf model [6] the unknown parameter $\gamma_A = 3$ determining the sea normalization can be obtain using Drell-Yan-West relation [9]. Using this value we get

$$G(x) = M x^{2.2} (1 - x)^{6.7}.$$

(6)

The structure function of the $c$-quark for the pentaquark $|uud\bar{c}\rangle$ [6] is shown in Fig. 1 by dotted line in comparison with the formula [2].

As we can see in Fig. 1 the probability distributions [2] and [6] are almost the same, under parameters we chose. The result is amazing — perturbative model [3] and our non-perturbative model, based on Regge trajectories of $c$-quarks give the same probability distribution. The question is appeared, how it could happen. We have one solution only:
The fraction momentum distribution of $c$-quark in the $|uud\bar{c}\rangle$ state: in the intrinsic charm model \cite{3} satisfied \cite{2} (solid line); in the alternative approach based on \cite{6} model satisfied \cite{6} (dashed line)

the presented in ref. \cite{3} probability distribution refers to the $c$-quark distribution in the pentaquark $|uud\bar{c}\rangle$ and has nothing to do with sea $c$-quarks.

We have one more argument in favor of the hypothesis. It is well known that the quark distribution functions in $K$-mesons and $\pi$-mesons are different. The difference can be explained by the model \cite{4} (see \cite{10}) on the one hand and by \cite{11} model on the other hand. It convinces us that the probability distributions \cite{2} and \cite{6} refer to the valence $c$-quark momentum distribution in the pentaquark $|uud\bar{c}\rangle$.

The next problem appeared is the proton-pentaquark mixing which determines absolute normalization. Let matrix element for $p \rightarrow |uud\bar{c}\rangle$ be equal to $V$, then admixture of the pentaquark in a proton is given by factor $V/(E_1 - E_2)$, where $E_1, E_2$ are energies of the pentaquark and the nucleon respectively. The matrix element can be evaluated as $\Lambda_{QCD}$ and the energy difference can be estimated as the difference of masses. In that way the probability to find the pentaquark in a proton is less than:

$$W(p \rightarrow uud\bar{c}) \leq \left( \frac{300 \text{ MeV}}{3 \text{ GeV}} \right)^2 \approx 1\%$$ \hspace{1cm} (7)

In fact we should expect the mixing to be much smaller. Most likely it is due to different color state of quarks in the pentaquark and in a proton. There are also experimental constraints on this parameter:

1. In the original work \cite{3}, based on assumption that most of the charm cross-section comes from diffraction in pp-interaction, the mixing was evaluated by 1%.
2. In the later work [11] the restriction 0.59% was given, based on data of European Muon Collaboration (EMC) in hadronic scattering. The best fit to data gave 0.31%.

3. Differential spectrum of $D$-mesons in photo-production processes [11] contradicts the intrinsic charm hypothesis and set the contribution restriction in the range of $\sim 0.1 - 0.2\%$.

4. The most severe restriction on the mixing hypothesis can be obtained by hidden charm particles production. Such analysis was performed in ref. [3]. According to this paper the upper bound in the $p \to |uudc\bar{c}\rangle$ probability is $\sim 10^{-7}$.

The discussed model, based on the assumption about the pentaquark-proton mixing, gives a consistent interpretation of the intrinsic charm phenomenon, which is used for the hadron physics application [1]. It is worth emphasizing that the observation of the intrinsic charm phenomenon can be result of existence of the stable pentaquark $|uudc\bar{c}\rangle$. A discovery of pentaquark $|uudc\bar{c}\rangle$ or getting more stringent restriction is a task of future experiments.

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