Near threshold production of a_0-mesons in the reactions $pp \to ppK^+K^-$ and $pp \to pnK^+\overline{K}^0$: Is the $a_0(980)$ a $q\bar{q}$ state or a threshold cusp?*

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In our recent paper [1] we have considered a_0 production in the reaction $\pi N \to a_0 N$ near threshold and at GeV energies. An effective Lagrangian approach as well as the Regge-pole model were applied to investigate different contributions to the cross section of the reaction $\pi N \to a_0 N$. The results have been used in Ref. [2] for an analysis of a_0 production in NN collisions. Within the framework of the one-pion exchange approximation the cross sections of the reactions $pp \to ppa_0^0$, $pp \to pna_0^+$, $pn \to pna_0^0$ and $pn \to ppa_0^-$ were expressed through two independent amplitudes of the reaction $\pi N \to a_0 N$ describing the channels with isospin I =1/2 and 3/2. It was found that near threshold the u-channel exchange mechanism with intermediate nucleon exchange gives the dominant contribution. This leads to the specific prediction that due to the favorable isospin Clebsh-Gordan coefficients the cross section of the reaction $pp \to pna_0^+$ is expected to be much larger than the one of the reaction $pp \to ppa_0^0$.

The production cross section in each channel depends on the cut-off parameter Λ_N for the virtual nucleon. In Refs. [1, 2] we used for the nucleon propagator (i.e. for the combined vertices a_0NN and πNN) the form factor $F_N(s) = \Lambda_N^4/[\Lambda_N^4 + (s-m_N^2)^2]$, which at large s behaves as $\simeq s^{-2} \simeq q_N^{-4}$. For brevity let's denote it by monopole form factor. In Ref. [1] we fixed Λ_N in the interval 1.2–1.3 GeV for the monopole form using experimental data on the forward differential cross section of the reaction $pp \to da_0^+$ at $3.8 \div 6.3$ GeV/c from Ref.[3] (see Fig.1).

Since there is no strict rule for the power of the nucleon form factor some authors (studying meson production in πN reactions) used a dipole form factor $[F_N(s)]^2$. Here we note that using a dipole form factor and readjusting the cut-off to the data of Ref. [3] only slightly modifies the results presented in Ref. [2]. In Fig. 1 we show the sensitivity of the forward differential cross section for the reaction $pp \to da_0^+$ to the choice of the nucleon and pion form factors. First of all, we see that an increase of $\Lambda_{\pi NN}$ from 1.05 to 1.3 GeV changes the cross section by about 30 % or less (compare the corresponding thin and bold curves). For the monopole nucleon form factor the Berkeley data from Ref. [3] can be reasonably fitted using $\Lambda_N = 1.2-1.24$ GeV (solid curves in Fig. 1). However, when employing a dipole FF with the same cut-off Λ_N, the predicted cross section will be lower than the data by a factor ~ 5 or more (lower long dashed curves in Fig. 1), which proves the cut-off to be inadequate in this case. The description of the data is regained (for the dipole FF) if we use $\Lambda_N = 1.55 - 1.6$ GeV (short dashed curves in Fig. 1). Therefore, using the Berkley data on the reaction $pp \to da_0^+$ we can fix the cut-off Λ_N for both cases: i.e. the monopole FF as well as the dipole FF.

The relevant question now is, if the resulting cross sections for the ppa_0^0 and pna_0^+ final states differ significantly. In Ref. [2] we calculated the total cross sections for four different channels of the reaction $NN \to NNa_0$

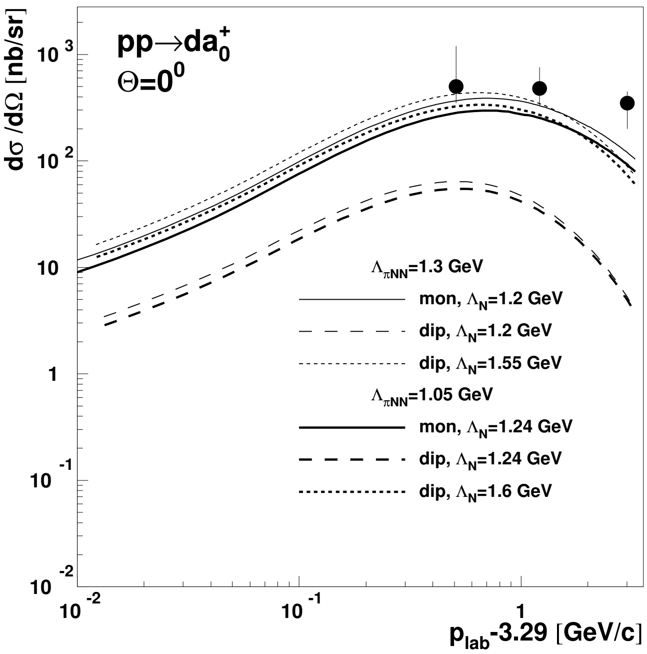

Fig. 1: Forward differential cross section of the reaction $pp \to da_0^+$ as a function of $(p_{lab} - 3.29)$ GeV/c. The bold and thin solid curves are calculated at $\Lambda_{\pi NN}$=1.05 and 1.3 GeV respectively. The solid curves correspond to a monopole nucleon form factor with Λ_N= 1.2 (thin) and 1.24 GeV (bold). The long-dashed and short-dashed curves are calculated using the dipole nucleon form factor for different values of Λ_N as shown in figure. The experimental data are taken from Ref. [3].

using a monopole nucleon FF with $\Lambda_N = 1.24$ GeV. If we take the dipole FF with the same Λ_N we again find the cross section to be 6–10 times smaller for the channels $pp \to pna_0^+$, $pn \to pna_0^0$, $pn \to ppa_0^-$, where the u-channel exchange mechanism is dominant and u-s interference is not very important. If we increase Λ_N to 1.55–1.6 GeV (as dictated by the Berkeley data) the cross sections are roughly the same as in the case of the monopole FF with $\Lambda_N = 1.24$ GeV (compare the solid and dotted curves). This behaviour of the cross section (with Λ_N) is very similar to the case of the reaction $pp \to da_0^+$. Only for the channel $pp \to ppa_0^0$ we find a slightly different cross section. For the dipole FF the cross section becomes somewhat larger than for the monopole FF, which is related to a strong destructive interference of the s- and u- exchange mechanisms. Due to this large cancellation of amplitudes by interference our predictions for the $pp \to ppa_0^0$ channel have a larger (systematic) uncertainty than for the other channels. Nevertheless, our basic result, that the a_0 production in the reaction $pp \to pnK^+\bar{K}^0$ will be much more abundant (by a factor of 10) than in the reaction $pp \to ppK^+K^-$ holds also in case of the dipole FF. This is demonstrated

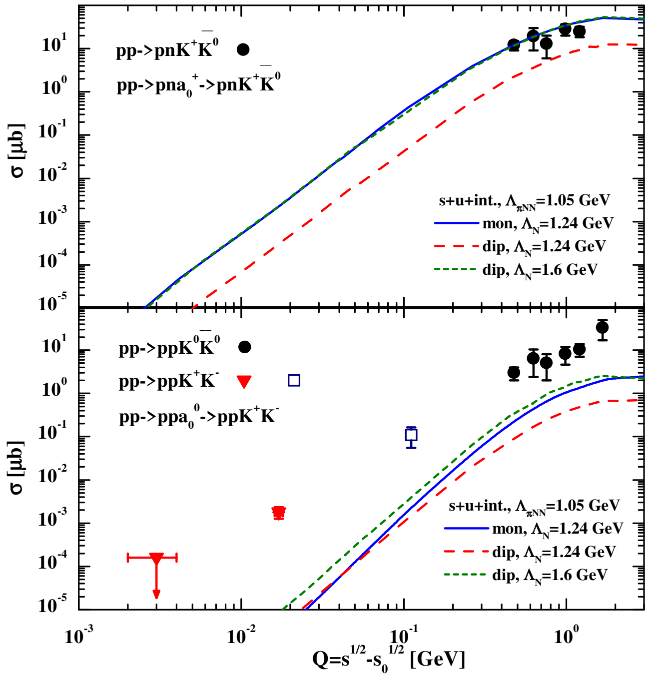

Fig. 2: Upper part: calculated total cross section for the reaction $pp \to pna_0^+ \to pnK^+\bar{K}_0$ in comparison to the experimental data for $pp \to pnK^+\bar{K}_0$ (solid dots) from Ref. [4] as a function of $Q = \sqrt{s} - \sqrt{s_0}$. The solid and long-dashed lines correspond to the coherent sum of the contributions from $s(N)$ and $u(N)$ channels with $\Lambda = 1.24$ GeV and are calculated using monopole (solid) and dipole (long-dashed) nucleon form factors; the short-dashed line is calculated using the dipole form factor with $\Lambda = 1.6$ GeV. Lower part: calculated total cross section for the reaction $pp \to ppa_0^0 \to ppK^+K^-$ as a function of $Q = \sqrt{s} - \sqrt{s_0}$ in comparison to the experimental data. The solid dots indicate the data for $pp \to ppK_0\bar{K}_0$ from Ref. [4], the open square for $pp \to ppK^+K^-$ from Ref. [5]; the full down triangels show the data from Ref. [6]. The legends of the lines are the same as in the upper part.

in Fig.2 where we display the calculated total cross sections for the reactions $pp \to pna_0^+ \to pnK^+\bar{K}^0$ and $pp \to ppa_0^0 \to ppK^+K^-$ as a function of $Q = \sqrt{s} - \sqrt{s_0}$ in comparison to the experimental data. For the a_0 mass distribution we used a Flatté formula with $\Gamma_{a_0\pi\eta}$=70 MeV and $BR(K\bar{K})$=0.187. We note also that our predictions for the cross sections $pp \to ppa_0 \to ppK^+K^-$ (using the dipole FF) do not exceed the upper limits on this cross section imposed by the DISTO data at $Q \simeq 100$ MeV and COSY-11 at $Q = 17$ MeV as well as by data at $Q \leq 2$ GeV. There is also no contradiction with the available data in other channels.

The structure of the lightest scalar mesons $a_0(980)$ and $f_0(980)$ is still under discussion. Different authors interpreted them as unitarized $q\bar{q}$ states or as four-quark cryptoexotic states or as $K\bar{K}$ molecules or even as threshold cusps. Experimental data on the a_0 production in NN collisions might give new information on the a_0 structure. According to Atkinson et al. [7] a relatively strong production of the a_0 (the same as for the $b_1(1235)$) in non-diffractive reactions can be considered as evidence for a $q\bar{q}$ state rather than a $qq\bar{q}\bar{q}$ state. For example the cross section of a_0 production in γp reactions at 25–50 GeV is about 1/6 of the cross sections for ρ and ω production. Similar ratios are found in the two-body reaction $pp \to dX$ at 3.8–6.3 GeV/c where $\sigma(pp \to da_0^+) = (1/4 \div 1/6)\sigma(pp \to d\rho^+)$ [3].
In our case we can compare a_0 and ω production. Our model predicts $\sigma(pp \to pna_0^+) = 30 \div 70$ μb at $Q \simeq 1$ GeV (see Fig. 7 in Ref.[2]) which can be compared with $\sigma(pp \to pp\omega) \simeq 100 - 200$ μb at the same Q. If such a large cross section could be detected this would be a serious argument in favour of the $q\bar{q}$ model for the a_0 meson.
To distinguish between the threshold-cusp scenario and a resonance model one can exploit different analytical properties of the a_0 production amplitudes. In case of a genuine resonance the amplitude of $\eta\pi$ and $K\bar{K}$ production through the a_0 has a pole and satisfies the factorization property. This implies that the shapes of the invariant mass distributions in the $\eta\pi$ and $K\bar{K}$ channels should not depend on the specific reaction in which the a_0 is produced (for $Q \geq \Gamma_{\rm tot}$). On the other hand, for the threshold cusp scenario the a_0 bump is produced through the $\pi\eta$ final state interaction. The corresponding amplitude has a square-root singularity and in general cannot be factorized (see e.g. Ref. [8] where the factorization property was disproved for pp FSI in the reaction $pp \to ppM$). This means that for a threshold bump the invariant mass distributions in the $\eta\pi$ and $K\bar{K}$ channels are expected to be different and will even depend on kinematical conditions (i.e. initial energy and momentum transfer) at the same excess energy, e.g. $Q \geq \Gamma$.

References:

[1] V.Yu. Grishina et al. Eur. Phys. J. A **9**, 277 (2000)
[2] E.L. Bratkovskaya et al., nucl-th/0107071
[3] M.A. Abolins et al., Phys. Rev. Lett. **25**, 469 (1970) S. Flatté, Phys. Lett. **B 63**, 224 (1976)
[4] Landolt-Börnstein, *New Series*, ed. H. Schopper, I/12 (1988)
[5] F. Balestra et al., Phys. Rev. C **63**, 024004 (2001)
[6] C. Quentmeier et al., Phys. Lett. **B 515**, 276 (2001)
[7] M. Atkinson et al., Phys. Lett. **B 138**, 459 (1984)
[8] V. Baru et al., Phys. Atom. Nucl. **64**, 579 (2001)

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