COHERENT PRODUCTION OF PARTICLES BY 67 GeV/c PROTONS ON EMULSION NUCLEI

M. G. ANTONOVA, E. G. BOOS, P. W. MOROZOVA, N. P. PAVLOVA, C. I. SHAKHOVA and Zh. S. TAKIBAEV
High Energy Physics Institute of the Kazakh Academy of Sciences, Alma-Ata, USSR

J. BABECKI, Z. CZACHOWSKA, B. FURMAŃSKA, R. HOŁYŃSKI, K. KARNICKA, S. KRZYWDZIŃSKI, G. NOWAK and K. RYBICKI
Insitute of Nuclear Physics, Cracow, Poland

O. E. BADAWY *, N. P. BOGACHEV, N. DALKHAZHAV, R. KHOSHMUKHAMEDOV **, J. M. KOHLI ***, G. S. SHABRATOVA and K. D. TOLSTOV
Joint Institue for Nuclear Research, Dubna, USSR

F. G. LEPEKHIN
Physical-Technical Institute of the Soviet Academy of Sciences, Leningrad, USSR

M. M. CHERNYAVSKY, N. B. MASLENNIKOVA, G. I. ORLOVA and M. I. TRETYAKOVA
Physical Institute of the Soviet Academy of Sciences, Moscow, USSR

K. I. ALEKSEEVA
Moscow State University, Moscow, USSR

S. A. AZIMOV, A. I. BONDARENKO, L. P. CHERNOVA, G. M. CHERNOV, K. G. GULAMOV, U. G. GULYAMOV, V. V. LAVKOV, V. Sh. NAVOTNY, T. T. RISKIEV, N. S. SKRIPNIK, N. S. SVECHNIKOVA and T. P. TROFIMOVA
Physical-Technical Institute of the Academy of Sciences of Uzbek SSR, Tashkent, USSR

and

C. BATAAR, B. CHADRAA, G. SHARKHUU, S. SUGAR and D. TUVDENDORZH
Institute of Mathematics and Physics of the Mongolian Academy of Sciences, Ulan-Bator, Mongolia

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Coherent reactions were observed among one-, three- and may be five-prong interactions of 37 GeV/c protons in nuclear emulsion. Their cross sections were estimated and compared with other data on coherent production in emulsion.

Coherent production of particles in proton-nucleus collisions is much less well known than in pion interactions (cf. the review paper by Bingham [1]). The main characteristics of this process do not depend on the nature of the incident particle. Due to low four-momentum transfer there is neither destruction, excitation,

* On leave of absence from Cairo University, UAR.
** On leave of absence from the Physical-Technical Institute, Dushanbe, USSR.
*** On leave of absence from the Punjab University, Chandigarh, India.

nor visible recoil of the target nucleus. Secondary particles are strongly collimated in the laboratory system. Baryon number, strangeness, isospin and charge of the coherently produced system are the same as those of the incident particle. For proton coherent interactions, contrary to those induced by pions, G-parity gives no restirction on the number of secondaries. Therefore the following coherent reactions can occur:

one-prong
$$p + A \rightarrow p\pi^0 + k\pi^0 + A \quad (1)$$
$$p + A \rightarrow n\pi^+ + k\pi^0 + A \quad (2)$$

three-prong
$$p + A \rightarrow p\pi^+\pi^- + k\pi^0 + A \quad (3)$$
$$p + A \rightarrow n\pi^+\pi^+\pi^- + k\pi^0 + A \quad (4)$$

five-prong
$$p + A \rightarrow p\pi^+\pi^+\pi^-\pi^- + k\pi^0 + A \quad (5)$$
$$p + A \rightarrow n\pi^+\pi^+\pi^+\pi^-\pi^- + k\pi^0 + A \quad (6)$$

etc, where A is a target nucleus in its ground state and $k = 0, 1, 2, 3 \ldots$.

In this letter coherent inelastic interactions of 67 GeV/c protons are described. They were studied in nuclear emulsion by this collaboration under the auspices of the Emulsion Committee of the Joint Institute for Nuclear Research. Preliminary results were reported at the Amsterdam Internatinal Conference on Elementary Particles [2]. The details of the experiment can be found in the preceeding paper [3].

Prong number distribution. On 3057m of proton tracks 1473 so-called proton-nucleon interactions were found. These are stars with at most one track in the forward laboratory hemisphere (usually a slow recoil proton) and without a visible recoil nucleus. The reader should be reminded here that in emulsion one can cbserve fairly slow recoils ($\sim$ 0.2 MeV protons and $\sim$ 1 MeV carbon nuclei). Coherent interactions (1) - (6) are among the so-selected events, with n_{ch} = 1, 3 and 5. The prong number n_{ch} distribution of our proton-nucleon interaction is shown in fig. 1. An overabundance of n_{ch} = 1 and n_{ch} = 3 stars is seen with respect to any smooth distribution starting from no events at n_{ch} = 0 and peaked at n_{ch} = 6, as could be expected for genuine proton-nucleon interaction. The prong-number distribution of the "clean" stars, i. e. those with neither a slow particle (grey track) nor an accompanying electron (which could come from the excitation of the target nucleus) is also shown in fig. 1. Coherent stars must be obviously "clean".

It is essentially the "clean" events which produce the excess of n_{ch} = 1 and n_{ch} = 3 stars. For $n_{ch} \geqslant 5$ there are systematically more "clean" p-p than p-n interactions which is connected with the presence of the emulsion hydrogen. At smaller values of n_{ch} we see just the opposite, this being connected with a strong admixture of coherent interactions in n_{ch} = 1 and n_{ch} = 3 events. A rough estimate of the number of the coherent three-prong events N_3 can be made assuming a linear increase in the plot dN/dn_{ch} versus n_{ch} in the region of n_{ch} = 2, 3 and 4. $N_3 = 82 \pm 14$ wa estimated in this way. The real value of N_3 will be even larger if there are more p-p than p-n events also in this region of n_{ch}.

Three-prong coherent events. Following the line of analysis used in our work on pion coherent interactions [4] we studied the distribution of the parameter $\sum_{i=1}^{3} \sin\theta_i$. This parameter, representing the degree of collimation of the secondaries, is roughly proportional to the longitudinal-momentum transfer $q_{\parallel}$ to the target nucleus [5]. The restriction $q_{\parallel} \lesssim \hbar/R_A$ (R_A being the radius of the emulsion nucleus) correspond to limiting $\sum_{i=1}^{3} \sin\theta_i$ by the values 0.2-0.4. It is seen in fig. 2. that this is the case for the majority of the "clean" three-prong stars.

Of cource not all "clean" three-prong events with $\sum_{i=1}^{3} \sin\theta_i < 0.3$ are coherent. In order to

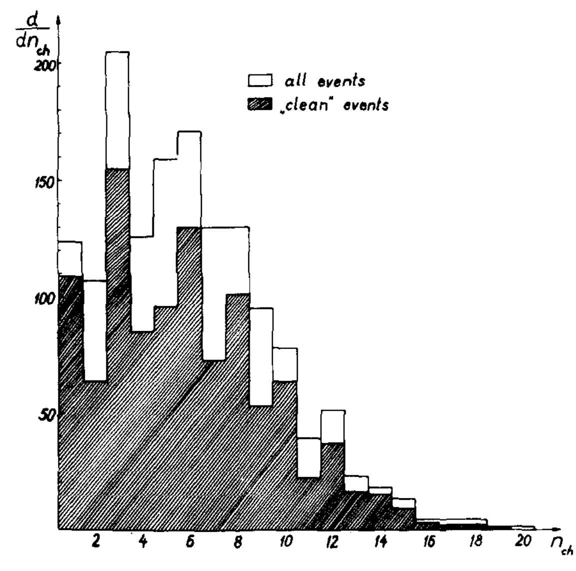

Fig. 1. Prong-number distribution of proton-nucleon interactions at 67 GeV/c. The hatched distribution corresponds to the "clean" events.

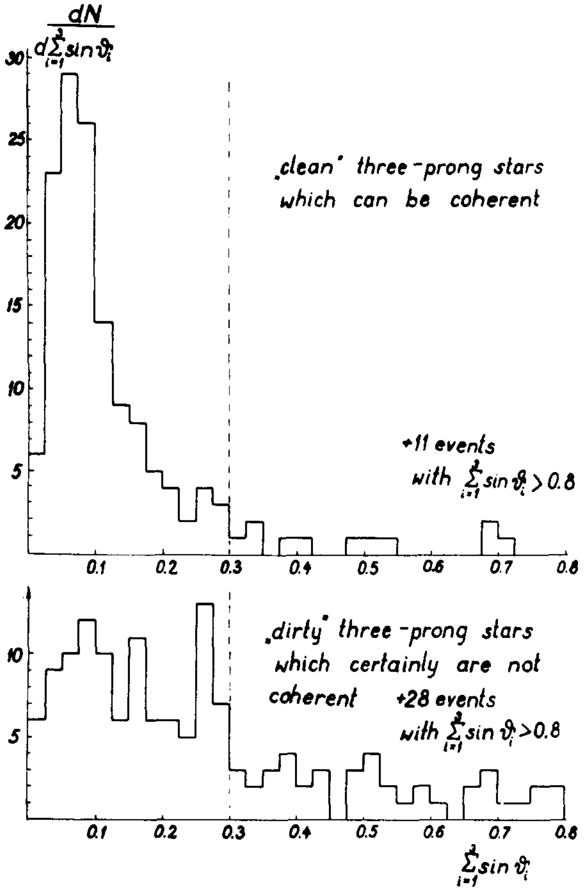

Fig. 2. Comparison of the $\Sigma_{i=1}^{3} \sin\theta_i$-distribution between "clean" (upper figure) and "dirty" (lower figure) three-prong stars. The vertical line at $\Sigma_{i=1}^{3} \sin\theta_i = 0.3$ shows the limit below which coherent events are expected.

substract the background, $\sum_{i=1}^{3} \sin\theta_i$ was calculated also for those ("dirty") three-prong stars which cannot be coherent i. e.

i) genuine p-n interactions accompanied by an electron,

ii) four-prong interactions in which the recoil-proton track has been omitted, thus imitating three-prong p-n stars. The recoil proton has been assumed to appear as a grey track or - if there is none - as largest-angle particle. The last assumption, if untrue, can lead to an underestimate of a number of coherent interactions N_3' obtained below.

The $\sum_{i=1}^{3} \sin\theta_i$-distribution of the "dirty" stars is also shown in fig. 2. By comparing the numbers of events below and above the value of $\sum_{i=1}^{3} \sin\theta_i = 0.3$ we obtained $N_3' = 103 \pm 14$. It should be pointed out that this estimate will be practically the same if one moves from 0.3 down to 0.15 or up to 0.5. A consistency between N_3' and N_3 is also to be noted. The value of N_3' corresponds to $\lambda_3^{67\mathrm{p}} = (29.6^{+5.5}_{-3.5})$m as the interaction length* for the three-prong coherent reaction in nuclear emulsion. For 60 GeV/c pions [4] the relevant value is $\lambda_3^{60\pi} = (16.5^{+1.3}_{-1.2})$m. The difference can be interpreted in terms of the different absorption of the incoming and outgoing waves. The cross section on a nucleon is much larger for a proton than that for a pion and the same is probably true for the $\mathrm{p}\pi^+\pi^-$-system as compared with $\pi^+\pi^-\pi^-$ - cf. refs [6] and [7]. Our value of $\lambda_3^{67\mathrm{p}}$ is much smaller than $\lambda_3^{20\mathrm{p}} = (63 \pm 12)$m obtained previously at lower energy using the same $\sum_{i=1}^{3} \sin\theta_i$ method [8]. An increase in the coherent cross section with increasing incoming momentum has also been observed previously for incident pions [4].

* For our emulsion there is the following relation between the coherent section σ_{coh} per emulsion nucleus and coherent-interaction length: $\sigma_{\mathrm{coh}}(\mathrm{mb}) = 207/\lambda(\mathrm{m})$.

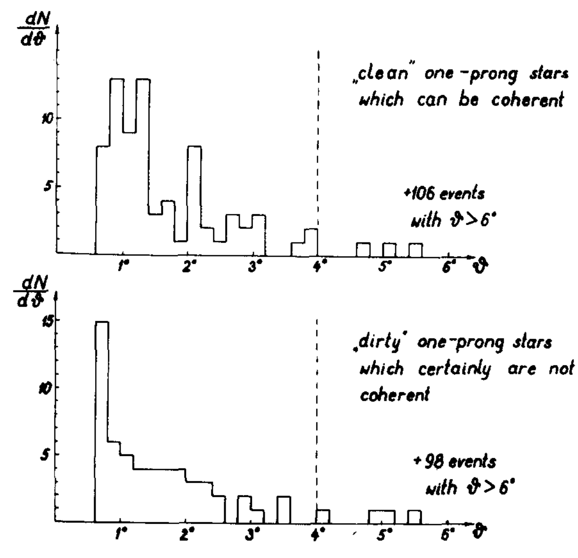

Fig. 3. Comparison of the deflection angle θ distribution between "clean" (upper figure) and "dirty" (lower figure) one-prong stars. The vertical line at $\theta = 4^{\circ}$ shows the limit below which coherent events are expected.

One-prong coherent interactions. Let us now go back to the one-prong coherent interactions. In order to get rid of the elastic events we consider only "clean" $n_{ch}=1$ stars with deflection angle smaller than 0.6^o, which leaves only ~ 1 elastic event. The deflection angles of these events are compared in fig. 3 with those of "dirty" events defined analogously as for three-prong stars. (This is essentially the $\sum \sin\theta$ - analysis.) It is seen that there are relatively fewer small deflection angles among "dirty" interactions. In our three-prong coherent interactions a large majority of angles is smaller than 4^o. Comparing the number of the "clean" and "dirty" one-prong events below and above this value one obtains $N_1 = 46.7 \pm 13.4$. Again this estimate will not change greatly of one takes 3^o or 5^o as the limiting angle. The above value of N_1 is obviously underestimated because such events can be lost in scanning. The relevant correction factor was estimated to be of the order of 1.5. Then the one-prong-coherent-interaction length becomes $\lambda_1^{67p} = 45$m. This is still overestimated because there can be a considerable number of coherent interactions with deflection angle less than 0.6^o, and all of them have been excluded as elastic scatters. It should be pointed out that we observe reactions (1) and (2) with cross section comparable (taking into account the above-mentioned losses) to that of the reactions (3) and (4). This can be interpreted in terms of the two-particle coherent production $p \to p\pi^0$ or $p \to n\pi^+$.

Five-prong coherent reactions. Finally, let us consider the reactions (5) and (6). Applying the same $\sum_{i=1}^{5} \sin\theta_i$ analysis the value $N_5 = 13 \pm 6$ was obtained. Due to low statistics we treat this result only as an indication that five-prong coherent reactions may occur at 67 GeV/c.

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