THE REACTION pp → pn π^+ AT 19 GeV/c DISCUSSED IN TERMS OF NUCLEON DISSOCIATION AND THE SPECTATOR-CONCEPT*

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By means of the concepts of nucleon dissociation spectator-behaviour and the impuls approximation the gross features of the reaction pp → pnπ^+ at 19 GeV/c incident momentum are well reproduced.

1. *Introduction*

The well known diffraction dissociation [1] and Deck [2] models assume that an incident particle may scatter on a target particle which originates from nucleon dissociation, N $\rightleftarrows$ N+π, as shown on the diagrams in Fig. 1a and 1b. The transition probability to

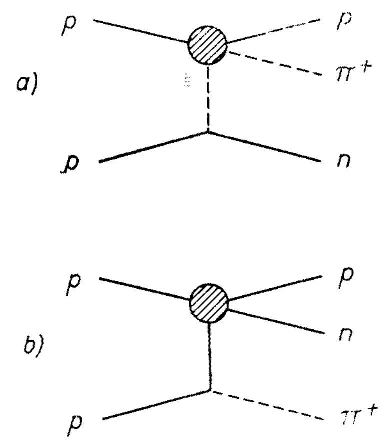

Fig. 1. Diagrams for diffraction dissociation

some specific final state configuration is formulated by means of an exchange in terms of a propagator or Regge-trajectory, some vertex functions or form factors, and a three-body phase space factor. In such a description of the reaction $p_ip \to p_i\pi^+n$, where p_i

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is an incident proton, the not directly scattered π^+ or n is more or less implicitly understood to behave spectatorlike [3], but this concept is usually not explicitly used in terms of a 3-vector in the description of the reaction. The intention with this note is tentatively to do so by analogy to pd-reactions, where one of the nucleons in the deuteron may behave spectatorlike, in order to study the kinematics of such a reaction in a perspicuous way.

We assume that by nucleon dissociation, the two-particle system $N+\pi$ has a space wave function with a corresponding momentum space representation, which implies that the two particles have Fermi-momenta. We furthermore assume that if one of these particles is removed from the system by means of some scattering, the other may retain most of its instantaneous Fermi-momentum, i.e., the impuls approximation is assumed to work.

Based on these assumptions it seems natural to write the transition probability to some specific final state configuration as the product of the probability for some specific spectator Fermi-momentum p_s, and the probability for some scattering in the remaining two-particle system. This two-body scattering at the upper vertex in Fig. 1 may be diffraction-like or resonance scattering, and we will in a simple way discuss some kinematical aspects for the reaction $pp \rightarrow pn\pi^+$ for both possibilities.

1.1. Some general features of this model

In the case of diffraction-like two-body scattering, the reaction $p_i p \rightarrow p_i \pi^+ n$ must be fairly energy independent since diffraction is fairly energy independent, and the spectator momentum is energy independent apart from some phase space restriction for the reaction.

When dissociation products like $n+\pi^+$ etc. in this way are freed, or "brought on the mass shell", the picture of the reaction is obviously very like "limiting fragmentation" [4]. Furthermore, since the identity of the incident particle is of little importance by diffraction scattering, some factorization should be expected for such reactions.

When some dissociated system in this way is "brought on the mass shell", the cross section for some specific reaction and the corresponding particle multiplicity should mainly express the probability for nucleon dissociation to this specific final state, e.g. $N \rightleftarrows N+\pi$, $N \rightleftarrows \Delta+\pi$, $N \rightleftarrows \Lambda^0+K$, etc.

The peripherality or leading particle property of this reaction is usually taken to be a consequence of a propagator- or trajectory-factor in the matrix element. On the other hand, if a spectator neutron retains its Fermi-momentum in the final state, this property follows automatically, not because of an exchange, but because the binding force has been broken.

2. *The reaction $pp \rightarrow p(n\pi^+)$ without resonance production*

While the conventional description of the Deck-mechanism takes the scattering at the upper vertex in Fig. 1a to be a scattering between an incident proton and "an off the mass shell pion", we think of this scattering in terms of a scattering between a proton and a bound pion with mass m_π. Therefore, at sufficiently high energy, the binding energy must be negligible.

2.1. Monte-Carlo simulation of diffraction-like $pp \to p(n\pi^+)$ events

We have Monte-Carlo generated events of the types

$$p + n_t\pi_s^+ \to p + n_t\pi_s^+ \tag{1}$$

and

$$p + \pi_t^+ n_s \to p + \pi_t^+ n_s \tag{2}$$

where the indices t and s mean target and spectator, respectively, according to the description given above in the following way. We choose by random an isotropic laboratory system spectator momentum $\vec{p}_s$. We assume that the function $f(p_s) = p_s \exp(-p_s^2/B)$, where $1/B = 3\,(\mathrm{GeV}/c)^{-2}$ reflects the nucleon dimension, in this preliminary study sufficiently well simulates the Fermi-momentum distribution function for n and π^+ in a dissociated nucleon.

We therefore assign to the generated event a weight $w_s = f(p_s)$, which gives the probability that a spectator shall have the momentum p_s.

From $\vec{p}_s$ and the incident proton momentum we calculate the mass of the $p\pi^+$ particle system. If this mass is outside the limits for the reaction, the generated event is discarded as outside the phase space.

We next generate an elastic collision between the beam-proton and the target-partner, i.e. $pn_t \to pn_t$ or $p\pi_t^+ \to p\pi_t^+$, according to the t-distributions $\exp(-10t)$ or $\exp(-6t)$, respectively, in the remaining pn_t or $p\pi_t^+$ system, where the momentum of the beam-proton is changed as little as possibie. This change, imposed to obtain overall energy momentum conservation, is of minor importance for high energy reactions. Hence, we also assign a weight $w_t = \exp(-10t)$ or $\exp(-6t)$ to the event. Since these exponents are phenomenologically introduced, we take the phase space factors to be included.

Hence, we assign a weight $w_D = w_s w_t$ to a diffractivelike Monte-Carlo generated event.

While the four-momentum given to the spectator is mainly a reflection of $f(p_s)$, the four-momentum t_p to the proton is a function of the energy and momentum given by the initial proton to the $n+\pi^+$ system

2.2. Comparison with the experimental results

We show in Figs 2 — 9 some characteristic distributions for the two Monte-Carlo generated reactions (1) and (2), and for the experimentally obtained results for the reaction $pp \to pn\pi^+$ at 19 GeV/c [5], when n and π^+ are restricted to the same cms hemisphere. As can be seen from Fig. 2, the function $f(p_s)$ restricted by energy and momentum conservation is a fairly good representation of the laboratory system momentum distributions, for both reactions (1) and (2).

However, the laboratory system angular distributions shown in Fig. 3 are definitely best reproduced when the neutron is taken to act as a spectator. The experimental $n\pi^+$ mass distribution is seen from Fig. 4 to be fairly well reproduced by both of the generated distributions. Resonance production in the $n\pi^+$ system is ignored in this discussion. As can be seen from Figs 5 and 6, the reaction generated with neutron spectator reproduces the observed Treiman–Yang and Jackson angular distributions best. Also, the distributions of $x = p_{||}^{cms}/p_{max}^{cms}$ for the pion agree well with the observations when the neutron is taken to act as a spectator, while the agreement is not so good when the pion itself is

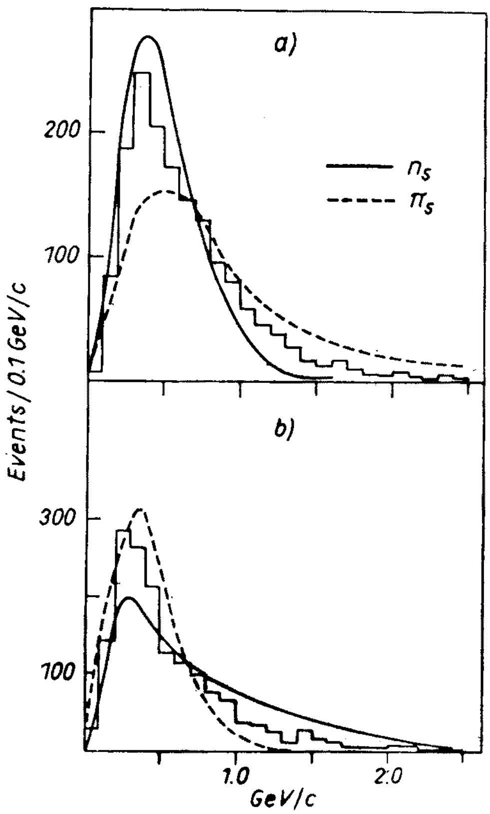

Fig. 2

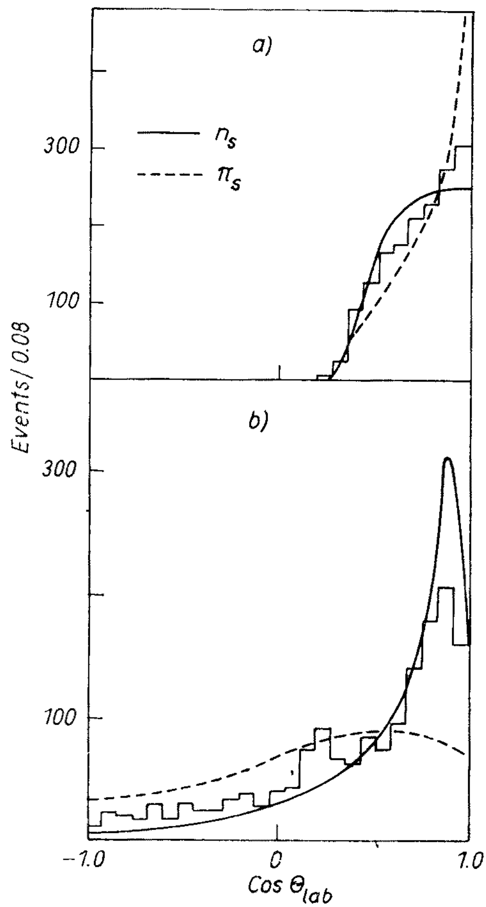

Fig. 3

Fig. 2. Experimental and generated distributions of the laboratory system momentum of a) neutrons and b) pions

Fig. 3. Experimental and generated laboratory system angular distributions for a) neutrons and b) pions

taken to act as a spectator, as seen from Fig. 7. The transvers momentum distributions for pions and protons are not very different for the two generated distributions, and they are both fairly similar to the observed ones, as shown in Fig. 8. However, while the $t'(p)$ distribution of four-momentum transfer to the proton is not quite well reproduced when the pion is taken to act as a spectator, the distribution generated with neutron spectator reproduces the observations very well, as can be seen from Fig. 9.

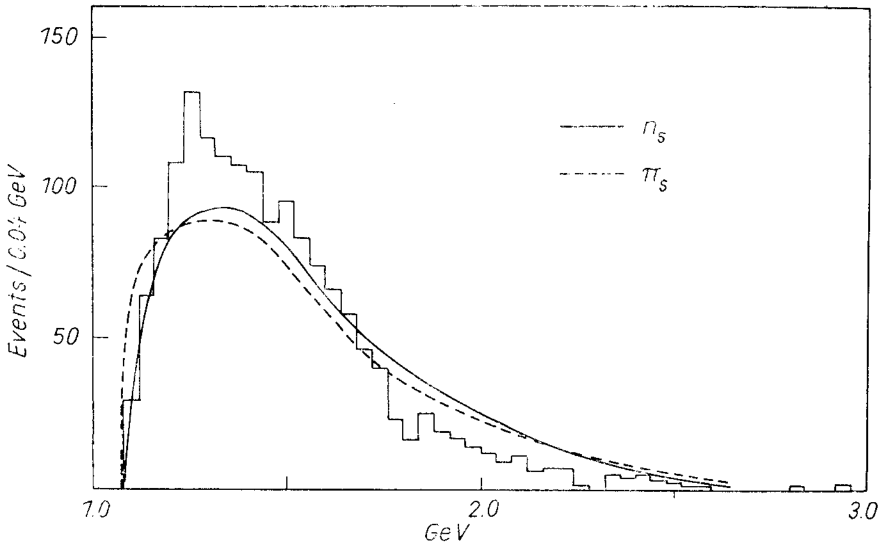

Fig. 4. Experimental and generated $n\pi^+$ effective mass distributions

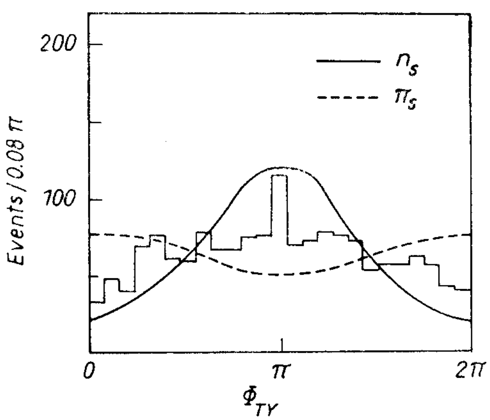

Fig. 5

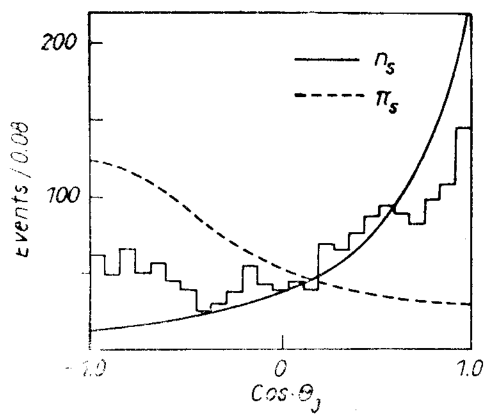

Fig. 6

Fig. 5. Experimental and generated Treiman-Yang angular distributions for the $n\pi^+$ system
Fig. 6. Experimental and generated Jackson angular distributions for n in the $n\pi^+$ system

Hence, the distributions generated with neutron spectator and pion target give the best agreement with the observed distributions. We will not in this preliminary report find the relative contributions of (1) and (2) to the reaction $pp \to pn\pi^+$ by means of fits. Possible resonance productions would then have to be taken into account.

However, as can be seen from the distributions, the simple spectator-model formulated by means of the function $f(p_s)$ and the impuls approximation, give the general features of the reaction $pp \to p(n\pi^+)$.

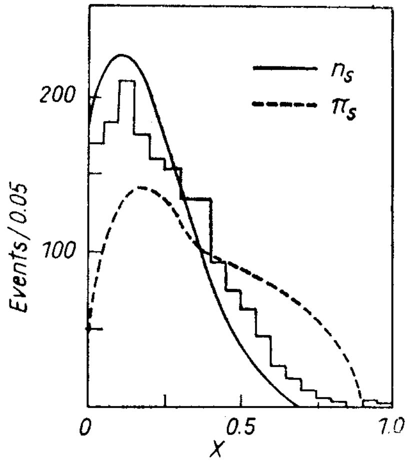

Fig. 7. Experimental and generated distributions pf $x = p_{\parallel}^{cms}/p_{max}^{cms}$ for pions

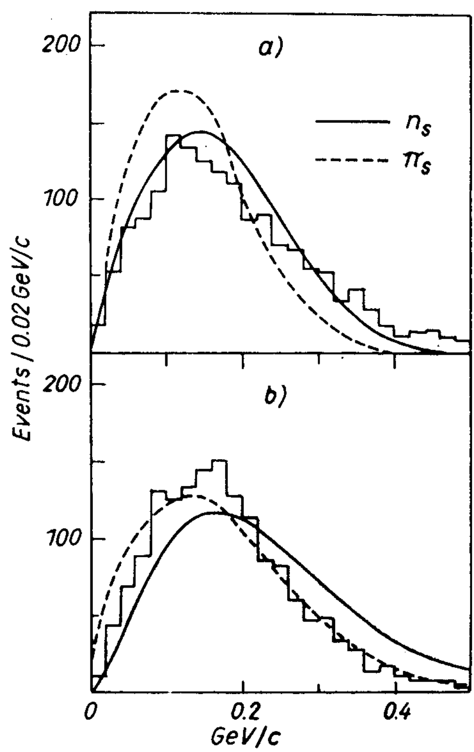

Fig. 8

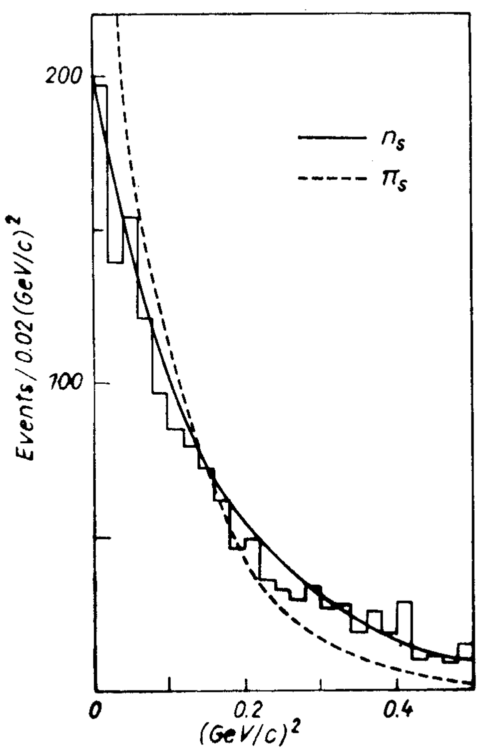

Fig. 9

Fig. 8. Experimental and generated distributions of the transversal momenta of a) pions and b) protons

Fig. 9. Experimental and generated distributions of $t'(p)$ to the proton

3. *Resonance scatterring* $p\pi^+ \to \Delta^{++}(1236)$

If the scattering in Fig. 1a is $p\pi^+$ resonance scattering through the $\Delta^{++}(1236)$ state, it is illustrative to think of the reaction $pp \to \Delta^{++}(1236)n$ by analogy to the stripping- and pickup-reaction $pd \to dp$, where an incident proton "steals" a neutron from the deuteron, i.e.

$$p+(\pi^+ + n) \to (p+\pi^+)+n = \Delta^{++}(1236)+n. \tag{3}$$

3.1. Monte-Carlo simulation of the reaction $pp \to \Delta^{++}n$

We have Monte-Carlo simulated the reaction $pp \to \Delta^{++}n$ according to our description of the transition probability above in the following way. We generate a spectator momentum $\vec{p}_s$ isotropically distributed in the laboratory system, and the event is given a weight $w_s = f(p_s)$.

From $\vec{p}_s$ and the incident proton momentum $\vec{p}_i$ we calculate the mass $m(p\pi^+)$ of the $p\pi^+$ system. If $m(p\pi^+)$ is outside the kinematical limits for the reaction, the generated event is discarded. We use a Breit–Wigner with a width 0.1 GeV to give a resonance weight w_r to an event, which thus gets a total weight $w_R = w_s \cdot w_r$.

3.2. t-distributions at 19 GeV/c

Events Monte-Carlo generated at 19 GeV/c incident proton momentum have t-distributions as shown in Fig. 10. It is interesting to note that for $|t| > 0.1$ (GeV/c)^2, $d \ln w(t)/dt$

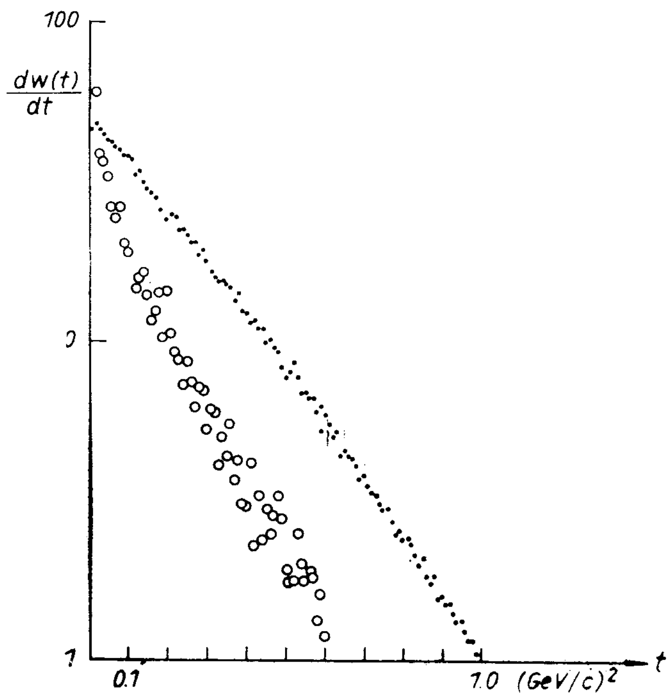

Fig. 10. Generated t-distributions: ● $\overline{w} = w_s$, ○ $\overline{w} = w_s w_r$

is an almost linear function of t with a slope about $-7\,(\mathrm{GeV}/c)^{-2}$. Hence, the geometrical--kinematical contribution to the experimentally obtained slope about $-15\,(\mathrm{GeV}/c)^{-2}$ may be large. Furthermore, for $w_R = w_s$ alone, the generated t-distribution is linear with a slope about $-3.5\,(\mathrm{GeV}/c)^{-2}$.

3.3. Cross section dependence of p

Since the weight w_R is a measure of the geometrical and kinematical constraints on the reaction $pp \to \Delta^{++}(1236)\,n$, we show in Fig. 11 the average weight $\bar{w}_R$ for samples of events Monte-Carlo generated at the incident momenta $p = 5, 10, 15, 20, 25, 30, 35$

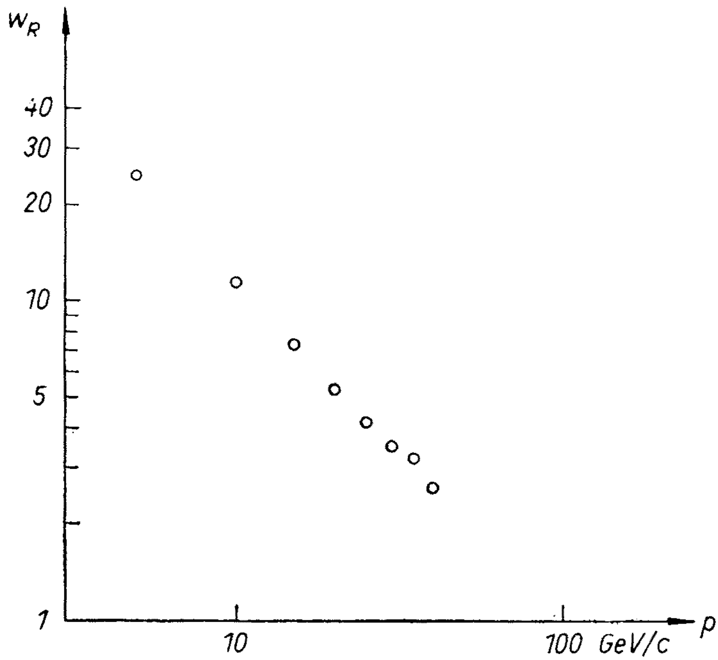

Fig. 11. Momentum-dependence of the average generated weight $\bar{w}_R$

and 40 GeV/c respectively. As can be seen, log $\bar{w}_R(p)$ is an almost linear function of log p, with a slope ≈ -1.

Hence, the kinematical and geometrical constraits on the reaction may contribute substantially to the experimentally [5] obtained slope n about -2, when $\sigma \propto p^n$.

4. Summary and conclusion

We have assumed that a dissociated (target) nucleon $N \rightleftarrows N+\pi$ has a space wave function with a corresponding momentum space representation, which implies that the two particles which originate from the dissociation have Fermi-momenta (p_s). If one of these particles is removed from this system by some scattering, and the other retains its Fermi-momentum p_s in the final state, the spectator-like behaviour of this particle may be taken explicitly into account in the description of the reaction.

In this way we have obtained a good description of the reaction $pp \rightarrow p(n\pi^+)$ at 19 GeV/c. Also, some interesting features are revealed concerning the t-dependence of the reaction $pp \rightarrow \Delta_{1236}^{++}n$ at 19 GeV/c, and the energy dependence of this reaction. It seems, therefore, as if a target proton may be represented by an energetically equivalent $n+\pi^+$ system which has a wave function, and that the impuls approximation works fairly well for the reaction $pp \rightarrow p\pi^+n$ at 19 GeV/c.

It should be noted that when the spectator-model is taken literally, the spectator--behaviour is not the consequence of some specific exchange to the spectator, but follows from the wave function of the dissociated system when the interaction between its particles is broken. This makes a difference between our description of the reaction $pp \rightarrow p\pi^+n$ and the exchange-model descriptions.

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