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Measurement of Two-particle Correlations in 800-MeV pA Collisions*

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ABSTRACT

Two-particle (p-p, p-d) coincidence has been measured in p + A collisions. Production mechanism of backscattered proton has been studied by forward-backward coincidence events. Data show the importance of 2N-cluster scattering and/or multiple scattering processes involving a few nucleons. They also show that the nucleon-nucleon quasi-elastic-scattering is not the dominant part of the backscattered proton production.

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Two-particle (p-p, p-d) momentum and angular correlations for 800 MeV protons on nuclear targets (C, NaF, KCl, Ag, and Pb) have been measured to study particle production mechanisms, especially in the energy region beyond free nucleon-nucleon kinematics. A magnetic spectrometer ($400 \leq P \leq 2000$ MeV/c, $15^{\circ} \leq \theta \leq 100^{\circ}$, $\phi = 0^{\circ}$), four sets of time-of-flight counter telescopes ($0.2 \leq \beta \leq 1$, $15^{\circ} \leq \theta \leq 90^{\circ}$, $\phi = 90^{\circ}$ and 180°), and three sets of Δ E-E counter telescopes ($300 \leq P \leq 600$ MeV/c, $100^{\circ} \leq \theta \leq 160^{\circ}$, $\phi = 90^{\circ}$ and 180°) were used to detect two particles emitted in the same reaction plane ($\Delta\phi = 180^{\circ}$) as well as two particles emitted out-of-plane ($\Delta\phi = 90^{\circ}$).

We report here only the data with one particle (proton, p, or deuteron, d) forward, $\theta_1 = 15^{\circ}$ and the other (p) backward, $\theta_2 = 118^{\circ}$.

Since no proton is backscattered in free nucleon-nucleon collisions, backscattering of proton in p + A collision must be due to nuclear effects. Single-particle inclusive cross-sections of the backscattered proton were measured with incident proton of 600 and 800 MeV[1] and 640 MeV[2]. The inclusive cross-sections as a function of momentum have exponential tails extending out to hundreds MeV/c. Several models such as the quasi-elastic-scattering (QES)[3], cluster scattering[4], cascade and statistical models[5], have been applied to explain the inclusive cross-sections with reasonable success. However, the success of these models, which are based on different assumptions, is an indication that the production mechanism of backscattered proton is not uniquely determined by the analysis of the inclusive cross-sections. Two-particle coincidence measurements have the advantage of more direct information about QES, cluster scattering and some of the other processes, and thus we expect such measurement to provide useful constraints on these models.

A two-proton coincidence experiment was reported by Komarov, et al.[6] suggesting the existence of two-nucleon (2N) cluster scattering process for the backward proton production. However, the importance of these processes as compared to others was not clear, because their measurement covered a rather narrow kinematical region which is biased in favor of 2N-cluster scattering processes.

The present measurement covers a much wider kinematical region which includes QES and 2N-cluster reactions. Since the 2N-cluster mechanism is closely related to deuteron production in the forward direction, a coincidence spectrum of a forward-going deuteron with a backscattered proton (d-p) was measured as well as the coincidence spectrum of two-protons (p-p). These coincidence spectra are measured in two modes, namely in-plane coincidence (IPC), (θ_1 = 15°, θ_2 = 118°, $\Delta\phi$ = 180°) and out-of-plane coincidence (OPC), (θ_1 = 15°, θ_2 = 118°, $\Delta\phi$ = 90°).

For all targets, more IPC events were observed than OPC events in both the p-p and d-p coincidences. This observation suggests that the backscattered protons are not emitted from an equilibrated system containing more than a few particles. Also incoherent multiple scattering which involves many particles is not likely to be the origin of the backscattered proton.

Fig. 1 a) and b) show the scatter plot of p-p and d-p IPC events in p + C reactions. Solid curves in the figures show the kinematics of p-p and d-p QES. The kinematic loci of the break-up of two and three nucleon clusters with zero excitation energy are represented by broken lines. The numbers along the curves indicate the initial momenta of the p, d or clusters inside the target nucleus. The IPC events show the clear existence of the p-p and p-d QES which are not seen in OPC. Besides the p-p QES, a broad but definite population is seen in the region of 2N-cluster break-up. In spite of the large excitation (300 400 MeV) of the remaining system, which includes all the particles other than detected ones, the number of IPC events are still larger than those of OPC. Fig. 2 shows the spectra of the backscattered proton associated with the different components, namely QES,[7] non-QES IPC, and OPC. All of the spectra, except d-p QES are fitted well by a function Ae^{-P/P_0} as in the case of the inclusive spectra. The slope factors for these spectra are tabulated in Table 1. The slope factor, P_0 of the p-p QES and OPC are smaller than that of the inclusive spectra. Because of the fast fall-off of the spectra, these two components cannot contribute significantly to the backscattered high-energy protons. The slope factors P_0 of in-plane p-p and d-p non-QES are similar to the P_0 of the inclusive spectra and hence suggest that there is a close relationship between these spectra. The difference spectrum between in-plane p-p non-QES and out-of-plane p-p is plotted in Fig. 3 as well as the proton spectrum associated with d-p QES. The two spectra are very similar in shape. If we consider OPC events as an isotropic background, a similarity of the spectra in Fig. 3 suggests that the excess in IPC is produced through a mechanism similar to that for deuteron production.

In conclusion, the fast fall-off of the p-p QES component indicates that quasi-elastic-scattering is not the dominant mechanism for producing backscattered high-energy protons. The dominance of the in-plane coincidence together with the steep slope of the spectra associated with the out-of-plane coincidence suggest that thermal or statistical equilibrium is not achieved. The similarity of the backscattered proton spectrum of d-p events and the difference spectrum between in-plane and out-of-plane coincidence events suggests the importance of scattering of the incident proton on correlated 2N-clusters. However, incoherent multiple scattering processes involving a few nucleons cannot be rejected at this stage of analysis. We need further analysis including angular distributions and also better theoretical calculations to distinguish these components.

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7) The QES component is defined rather arbitrarily here as the events in which the excitation of residual nuclear system is less than 100 MeV.

TABLE 1

Slope factors P_0 of backscattered proton spectra in 800 MeV p + A collisions

(P_0 in MeV/c)

Target		C	KCl	Pb
inclusive		88 ± 1	87 ± 2	85 ± 2
in-plane coincidence	p-p QES	56 ± 4	55 ± 3	56 ± 4
	p-p non-QES	85 ± 5	98 ± 5	92 ± 4
	p-d non-QES	-	94 ± 8	84 ± 9
out-of-plane coincidence	p-p all	72 ± 5	71 ± 3	80 ± 4
	p-d all	63 ± 20	73 ± 7	77 ± (8)

The backscattered proton spectra are fitted by a function:

$$\frac{d\sigma}{dpd\Omega} = Ae^{-P/P_0}$$

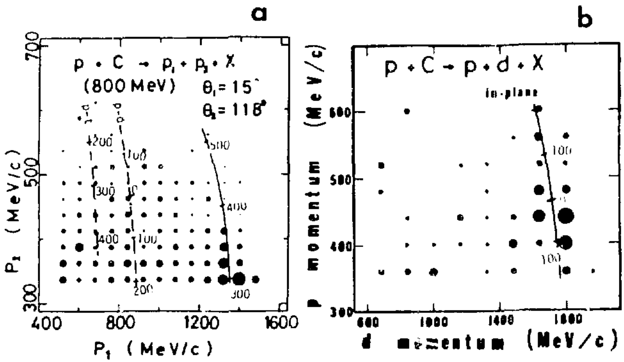

Fig. 1 Momentum-momentum scatter plot of the p-p (a) and p-d (b) events of in-plane-coincidence mode. The area of circle in the figure is roughly proportional to the number of events.

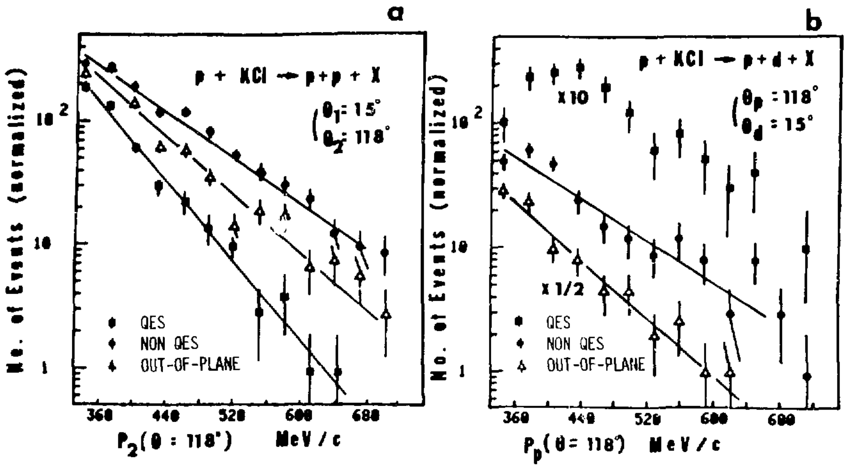

Fig. 2 Spectra of the backscattered protons for different components. Solid lines are the exponential fit to the data.

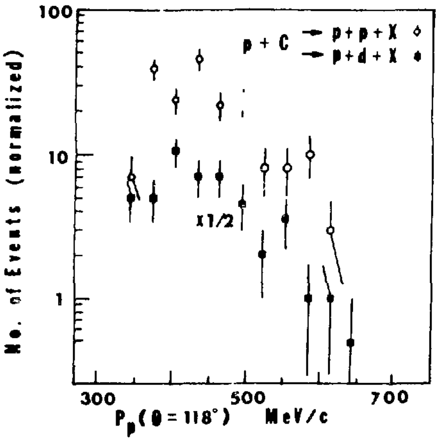

Fig. 3 The backscattered proton spectra associated with d-p quasi-elastic-scattering and the difference between in-plane p-p non-QES and out-of-plane p-p coincidences.