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Evidence for sideward emission of Sc fragments in the interaction of ^{238}U with 400 GeV protons*

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Thick-target recoil properties of Sc fragments produced in the interaction of ^{238}U with 400 GeV protons have been determined. The anisotropy parameter, b/a, was obtained from measurements on targets oriented either parallel or perpendicular to the proton beam on the assumption that the angular distribution of the fragments in the moving system has the form $a + b \cos^2\theta$. The weighted average value of b/a for four Sc nuclides is -0.67 ± 0.12 indicating that the angular distribution must show strong sideways peaking.

NUCLEAR REACTIONS $^{238}U(p,f)$ $^{44}Sc^m$, ^{46}Sc, ^{47}Sc, ^{48}Sc, $E_p = 400$ GeV. Measured thick-target recoil properties; deduced anisotropy parameter.

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In a recent study of the energy dependence of the recoil properties of Sc nuclides formed in the interaction of ^{238}U with high-energy protons[1] it was found that the ratio of forward-to-backward emission (F/B) decreased practically to unity at 300 GeV. This result was surprising as it implied that at the highest bombarding energies available the struck nuclei which eventually formed Sc products acquired virtually no forward momentum. Although the F/B values of products requiring high deposition energies for their formation generally[2,3] peak at approximately 3 GeV and decrease continuously thereafter, the Sc nuclides appeared to have unusually low F/B at 300 GeV. It was suggested[1] that these low F/B might be associated with sideways peaking of the angular distribution, possibly due to a shock wave initiated by the ultra-relativistic proton[4]. Recent measurements[5] of the angular distribution of light fragments emitted in reactions of U and Au with 28 GeV protons do in fact reveal a peak near 90°.

In order to obtain additional information about this novel phenomenon angular distribution measurements must be performed at 300 GeV. While we plan to perform such measurements in the future it appeared desirable to obtain some qualitative information about the angular distribution as rapidly as possible. The thick-target recoil technique, in which the fraction of products recoiling out of a target placed perpendicular to the beam is compared with that recoiling out of a target oriented parallel to the beam, yields such information[6,7]. We have performed such an experiment on Sc nuclides formed in the interaction of ^{238}U with 400 GeV protons.

Three replicate irradiations of a target stack oriented parallel to the beam[8] and one irradiation with the stack perpendicular to the beam were performed with 400 GeV protons in the meson hall at Fermilab. The target stack consisted of a 20 μm thick depleted uranium foil surrounded by a pair of 20 μm thick 99.999% pure Al catcher foils and was sealed in an evacuated plastic bag.

Following irradiation scandium was separated from the target and catcher foils and assayed by a Ge(Li) spectrometer. The details of the experimental procedure have been published[1].

The results are summarized in Table I. Since the data obtained in the perpendicular experiment agreed with the results of two experiments previously performed at 300 GeV[1] we have averaged the three sets of data in order to obtain the greatest statistical accuracy. The tabulated quantities, all of which are expressed in mg/cm^2 of uranium, are defined as $R_+ = 2W(F+B)$, $R_- = W(F-B)$, and $R_\perp = 2WP$. R_+ and R_- are obtained from the perpendicular orientation experiments and F and B are the fraction of the total radioactivity due to a given nuclide observed in the forward or backward catchers, respectively. $R_\perp$ is obtained from the parallel experiment and P is the sum of the fractional radioactivity collected in the two sideward catchers. The target thickness is designated W. The quoted uncertainties are based on the agreement between replicate determinations and are consistent with the precision of the data. A 6% correction for scattering at the target-catcher interface has been applied[7]. It is seen that the values of $R_\perp$ are substantially larger than those of R_+ indicating preferential fragment emission at sideward angles.

The data may be analyzed by equations based on the two-step velocity vector model[6,7] to yield the average range of the fragments in the moving system, R, the ratio of the forward component of velocity of the moving system to the velocity of the fragment in the moving frame, $\eta_{/\!/}$, and the anisotropy parameter, b/a, where the angular distribution of the fragments in the moving system is assumed to have the form $a + b\cos^2\theta$. The equations relating the measured recoil properties to these parameters have been published elsewhere[7] and we have used an iterative procedure to obtain the solutions. In addition to the measured recoil properties the analysis requires the value of the exponent in the range-velocity relation for the fragments. This relation can be expressed as $R = kV^N$ where $N = 1.54$ for Sc fragments[1]. One remaining parameter that enters into the analysis is the value of $\eta_\perp$, the ratio of the transverse component of velocity of the moving system to the velocity of the fragment. Our previous analysis[1] suggested that $\eta_\perp$ might perhaps be five times larger than $\eta_{//}$. However due to the very small values of $\eta_{//}$ obtained in this experiment $\eta_\perp$ is sufficiently small so that the results are virtually identical with those obtained for $\eta_\perp = 0$.

The results of this analysis are summarized in Table I. The values of b/a are of special interest. Within the limits of error the values are the same for all four Sc nuclides, the weighted average being -0.67±.12. These negative anisotropy coefficients are far larger in magnitude than any other previously reported values for high-energy reaction products[7,9] and indicate that the angular distributions must show strong sideways peaking. As an example, Figure 1 shows the laboratory angular distribution expected for ^{48}Sc on the basis of the measured b/a and $\eta_{//}$ values. The expected ratio of differential cross sections at 90° and 0° to the beam is 2.6. Included in this figure is the angular distribution of Mg fragments emitted in the reaction of ^{238}U with 28 GeV protons[5]. It is apparent that the increase in energy and/or fragment mass leads to a substantial increase in anisotropy. It must, of course, be pointed out that the angular distribution of ^{48}Sc at 400 GeV need not necessarily look exactly like the curve in Fig. 1 since the latter is derived from a thick-target experiment and an assumed parametrization of the angular distribution. Our results do indicate that angular distribution measurements at ultra-high energies will prove to be of great value to an understanding of these reactions.

The present analysis of thick-target recoil data in which the effect of anisotropy is included reveals that the recoil ranges in the moving system are some 15% larger than the measured R_+ values. Previous studies[1,3,10] have shown that the R_+ of a large number of ^{238}U reaction products decrease by 5-10% between 11.5 and 300 GeV. The present results suggest that this decrease may actually be a reflection of possible changes in the angular distribution rather than a range effect. Angular distribution data are necessary before such relatively small effects can be definitively interpreted.

References

1. Ø.Scheidemann and N. T. Porile, Phys. Rev. C (in press).
2. K. Beg and N. T. Porile, Phys. Rev. C3, 1631 (1971).
3. S. B. Kaufman and M. W. Weisfield, Phys. Rev. C11, 1258 (1975).
4. A. E. Glassgold, W. Heckrotte, and K. M. Watson, Ann. Phys. (New York) 6, 1 (1959).
5. L. P. Remsberg and D. G. Perry, Phys. Rev. Lett. 35, 361 (1975).
6. N. T. Porile and N. Sugarman, Phys. Rev. 107, 1410 (1957).
7. N. Sugarman, H. Münzel, J. A. Panontin, K. Wielgoz, M. V. Ramaniah, G. Lange, and E. Lopez-Menchero, Phys. Rev. 143, 952 (1966).
8. The target stack was actually oriented at 10° to the beam in order to keep the effective target thickness from becoming too large. The effect of this tilt on the analysis of the data is neglibigly small.
9. V. P. Crespo, J. B. Cumming, and A. M. Poskanzer, Phys. Rev. 174, 1455 (1968).

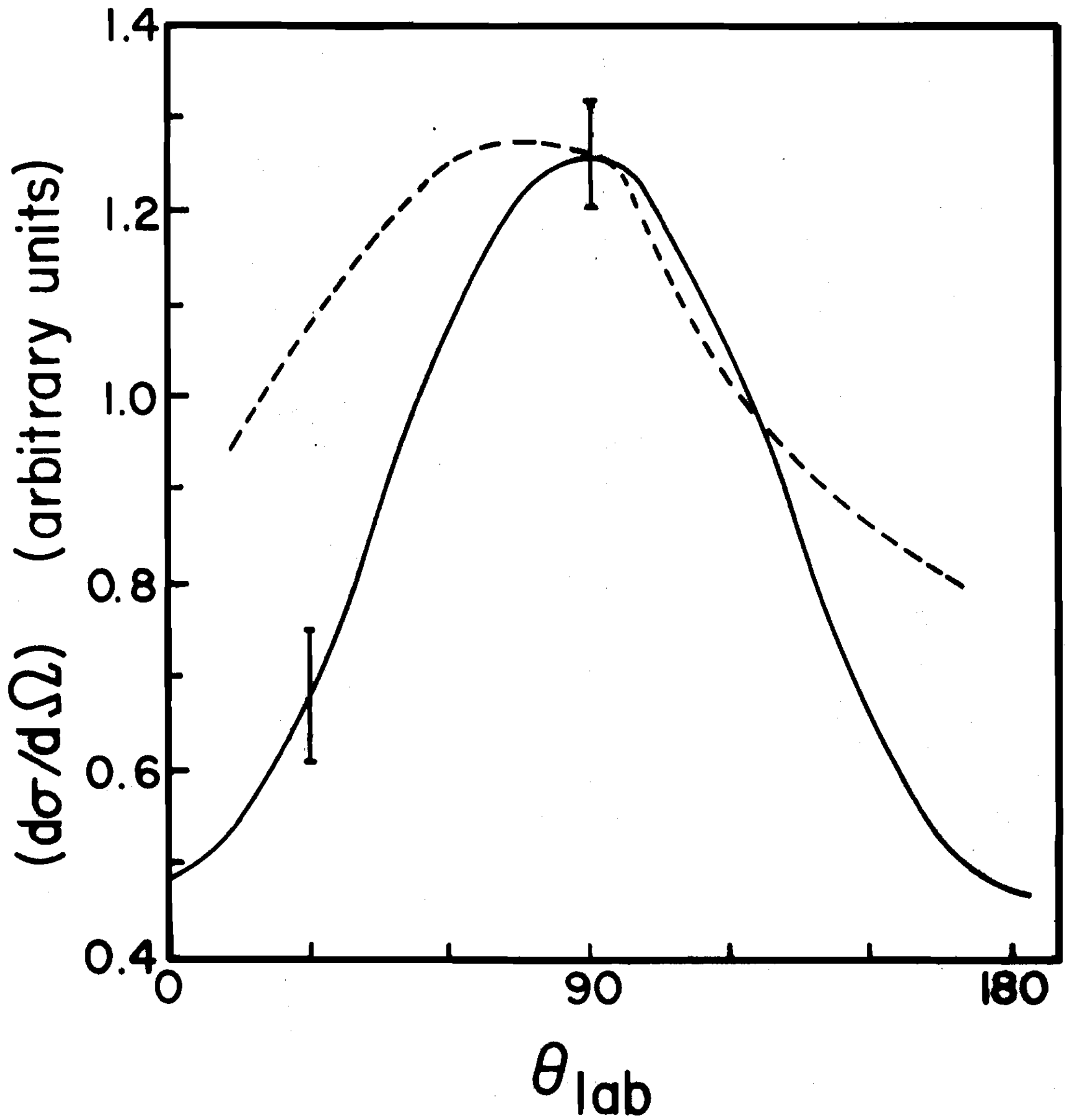
S. K. Chang and N. Sugarman, Phys. Rev. C9, 1138 (1974).

Table 1. Recoil properties and parameters of Sc nuclides formed in the interaction of ^{238}U with 400 GeV protons

Nuclide	R_+ (mg/cm^2)	R_- (mg/cm^2)	$R_\perp$ (mg/cm^2)	R (mg/cm^2)	$\eta_{\parallel}$	b/a
$^{44}Sc^m$	8.14±.23	0.098±.087	10.45±.43	9.68±.30	0.0090±.0079	-0.72±.11
^{46}Sc	8.79±.62	0.29±.46	10.88±.48	10.18±.78	0.0025±.0040	-0.62±.20
^{47}Sc	8.89±.38	0.11±.14	11.12±.38	10.38±.48	0.0096±.0119	-0.66±.12
^{48}Sc	9.10±.29	0.070±.024	11.16±.38	10.47±.36	0.0059±.0020	-0.62±.11

Figure Captions

Figure 1. Laboratory angular distribution of ^{48}Sc formed in the interaction of ^{238}U with 400 GeV protons as expected from the measured b/a and $\eta_{//}$ values. The error bars show the uncertainties expected from that in b/a. The dashed curve represents the measured angular distribution of Mg fragments from the interaction of ^{238}U with 28 GeV protons[5]. The two curves have been normalized at 90°.



1.4
1.2
1.0
0.8
0.6
0.4
0
90
180
(dσ/dΩ) (arbitrary units)
θlab