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Publication Date
1975-10-01

Submitted to Physical Review Letters

LBL-4309 Rev.
Preprint c.1

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October 1975

Prepared for the U. S. Energy Research and
Development Administration under Contract W-7405-ENG-48

Submitted to Phys. Rev. Letters LBL-4309 Rev.

SEARCH FOR FRAGMENT EMISSION FROM NUCLEAR SHOCK WAVES*

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ABSTRACT

Energy spectra and angular distributions have been measured of ^{3}He and ^{4}He fragments emitted from Ag and U targets, bombarded with protons of 2.7 GeV, and α particles and ^{16}O ions of 1.05 GeV/nucl. All cross sections increase dramatically with projectile mass. No narrow peaks are found in the angular distributions or in the energy spectra.

For central collisions of nuclei at relativistic energies, recent theoretical investigations[1-6] have focused on the question of how large amounts of energy and momentum are transferred from projectile to target nucleons, and on the early events in the evolution of hot, high density regions as thermal equilibrium is approached. In particular, the formation of squirts of nuclear matter, or of nuclear shock waves[7] carrying large transverse momentum and compressional energy have been predicted[2-5]. These would be formed in central collisions if the projectile velocity exceeds the nuclear sound velocity $\nu_o \approx 0.2c$. The models are in disagreement about the angles in the lab system at which emission should occur, some predicting[3,4] a narrow peak at angles ranging from 25° to 45° depending systematically on the incident energy while others anticipate a broad range of forward angles for the fragments[5]. There is agreement, however, as to the expectation that such processes should have a high fragment multiplicity, with energies ranging far above the evaporative domain.

In an experiment with Lexan foil detectors, Crawford et al.[8] investigated fragments resulting from the interaction of a 2.1 GeV/nucl ^{12}C beam with Au. Non-evaporative tails in the spectra were observed but angular distributions showed no significant peaks. Kullberg and Otterlund[9] have studied the emission of α particles produced in nuclear emulsions by heavy cosmic ray nuclei. The angular distributions deviate markedly from evaporation model predictions at angles around 45°. The authors observe that the high energy α particles result primarily from high multiplicity (star event) target fragmentations.[10]

The most provocative experiment thus far is a recent study of prong angular distributions of star events produced in AgCl crystals irradiated with 0.87 GeV/nucl ^{16}O ions by Schopper's group at Frankfurt.[3] They report the observation of narrow peaking in $d\sigma/d\theta$ at 40°, with an angular width of about 20° (FWHM). The prongs analyzed in that experiment are due to protons less than 28 MeV and He nuclei less than 200 MeV/nucl, with no further discrimination with respect to energy and isotope. The peak is only pronounced when data with large prong multiplicity are selected.

We have therefore undertaken a study at the Bevalac of target fragment energy spectra and angular distributions with a ΔE-E counter telescope that would identify He fragments with 15 ⩽ E/nucl ⩽ 150 MeV. The beams used were protons of 2.7 GeV, α particles of 0.7 and 1.05 GeV/nucl and ^{16}O ions of 1.05 GeV/nucl. Average particle fluxes were 10^8 particles per beam burst. Targets of natural silver and uranium, about 200 to 300 mg/cm^2 thick, were mounted in a scattering chamber equipped with a detector telescope consisting of a 1 mm thick Si transmission counter as a ΔE detector, and a 5 cm thick plastic scintillator (Pilot B) coupled to a 2.5 cm diameter phototube as an E detector. The telescope was mounted 25 cm from the target and subtended a solid angle of 5 msr.

The energy calibration of the spectra was obtained for each kind of particle from the ΔE signals in the surface barrier detector, using the known relation between energy loss in the ΔE counter and total kinetic energy. The overall energy resolution was better than 5%. The accessible energy range in MeV/nucl for ^3He and ^4He ions stopped in the second detector was 20 to 95 and 15 to 80, respectively. However, owing to the good separation of ^3He and ^4He branches in the ΔE-E plot, it was possible to identify ^3He particles that were not completely stopped, following their spectra up to about 160 MeV/nucl.

The beam intensities were monitored[11] with an ionization chamber assuming that its output is proportional to Z^2. The relative cross sections from the proton, ^4He and ^{16}O beams on the same target, should be accurate to better than 20%. The overall normalization of the absolute cross section scale was determined within ±50% by matching the present data to spectra obtained previously in the vicinity of the low energy evaporation peaks.[12]

Spectra are shown in Fig. 1 for ^3He and ^4He emission at 20° in the lab system from a U target bombarded with several projectiles and energies. For energies above 50 MeV/nucl, the cross sections increase by more than an order of magnitude as the projectile changes from p to ^4He, and from ^4He to ^{16}O. The ^3He spectrum from ^{16}O + U is remarkably flat, with cross sections above 1 mb/MeV·sr even at 150 MeV/nucl.

A comparison of ^3He and ^4He double differential spectra from the ^{16}O + U interaction is shown in Fig. 2. The ^4He spectra decay much faster towards higher energies than the ^3He spectra, with the latter showing higher cross sections above about 30 MeV/nucl. It is obvious that the spectra cannot be understood by a simple evaporation process because the "nuclear temperatures" (60 MeV for ^3He, 38 MeV for ^4He) are far too high.

From Fig. 2 it is clear that the angular distributions do not show pronounced maxima. At about 20 MeV/nucl the differential cross sections are only somewhat forward peaked, but at higher energies they are strongly forward peaked. For ^3He produced from ^{16}O + Ag, the angular distributions are shown in Fig. 3 for four successive bins of energy. We have plotted $d\sigma/d\theta = d\sigma/d\Omega \sin\theta$ here only in order to facilitate a comparison with the data of Baumgardt et al.[3] The peak in $d\sigma/d\theta$ has a width of about 60° (FWHM); its position shifts from 58° in the low energy bin to about 30° above 100 MeV/nucl where the angular distributions show little further change in shape. The same behaviour is observed for all other combinations of target, projectile and reaction product. No narrow peaking comparable with the 20° width observed by Baumgardt et al. is found. If one assumes the correspondence reported by Kullberg and Otterlund[9] between high energy He emission and high prong multiplicity, our data are in disagreement with those of Baumgardt et al. concerning the shape of the angular distributions. The angular distributions, as $d\sigma/d\Omega$, integrated over all energies detected in this experiment are given in Fig. 4. They show forward peaking with leveling off towards angles $\theta \leqslant 40^\circ$. The preliminary numerical calculations[5] of the two dimensional relativistic hydrodynamics for the ^{16}O + Ag interaction are in qualitative agreement with these angular distributions, but the energy spectra do not agree.

Even though our data are not selected for high multiplicity events we may still compare our absolute cross sections to those of Baumgardt et al. For their 20° wide peak at 40° they report[13] $d\sigma/d\Omega = 0.7$ b/sr. It would be difficult to hide such a peak under the smooth curves in Fig. 4 for 1 GeV/nucl ^{16}O on Ag. In addition, if their cross section were spread uniformly over their observable energy range of 200 MeV/nucl, $d^2\sigma/d\Omega dE$ would be about 1 mb/MeV-sr. Our curves for the Ag target (like those in Fig. 2 but down by a factor of $2\frac{1}{2}$) are smooth in both energy and angle, and at 40° drop below this value at 35 and 60 MeV/nucl for ^4He and ^3He, respectively. Thus we may conclude, without any assumptions about high multiplicity stars, that the events of Baumgardt et al. are not dominately due to high energy He nuclei.

In conclusion, our data present evidence for the non-evaporative emission of ^3He and, to a somewhat lesser extent, ^4He products in collisions between relativistic heavy ions. The cross sections for these high energy products are two to three orders of magnitude higher than those found for proton induced reactions at comparable incident velocity.[14] This points towards a cooperative mechanism that cannot be explained by geometrical considerations or by an independent superposition of nucleon induced knockon cascades.

We would like to thank Drs. W. Greiner, E. Schopper, J. R. Nix, and P. G. Siemens for useful discussions.

FOOTNOTE AND REFERENCES

*Work performed under the auspices of the U.S. Energy Research and Development Agency, and the Bundesministerium für Forschung and Technologie, German Fed. Rep.

1. W. Scheid, H. Müller and W. Greiner, Phys. Rev. Lett. 32, 741 (1974) W. Greiner, in Proc. 2nd High Energy Heavy Ion Summer Study, L. Schroeder, editor, LBL 3675.

2. C. Y. Wong and T. A. Welton, Phys. Letters 49B, 243 (1974).

3 H. G. Baumgardt, J. U. Schott, Y. Sakamoto, E. Schopper, H. Stocker, J. Hofman, W. Scheid and W. Greiner, Z. Physik A273, 359 (1975).

4. M. J. Sobel, P. J. Siemens, J. P. Bondorf and H. A. Bethe, Niels Bohr Institute Preprint (1975).

5. A. A. Amsden, G. F. Bertsch, F. H. Harlow and J. R. Nix, Phys. Rev. Letters 35, 905 (1975), and J. R. Nix, private communication (1975).

6. G. Chapline, M. Johnson, E. Teller and M. Weiss, Phys. Rev. D8, 4302 (1973).

7. A. E. Glassgold, W. Heckrotte, and K. M. Watson, Ann. Phys. 6, 1 (1959).

8. H. J. Crawford, P. B. Price, J. Stevenson and L. W. Wilson, Phys. Rev. Lett. 34, 329 (1975).

9. R. Kullberg and I. Otterlund, Z. Phys. 259, 245 (1973).

10. B. Jakobsson, R. Kullberg and I. Otterlund, Z. Phys. 268, 1 (1974).

11. A. M. Zebelman, A. M. Poskanzer, J. D. Bowman, R. G. Sextro and V. E. Viola, Phys. Rev. C4, 1280 (1975).

12. A. M. Poskanzer, A. Sandoval, R. G. Sextro and A. M. Zebelman, to be published.

13. E. Schopper, private communication (Oct. 1975).

14. At incident proton energies of about 30 GeV, a high yield of ^{3}H and ^{3}He has also been observed that was interpreted as an emission from hadronic fireballs (R. Hagedorn and J. Ranft, Nuovo Cimento Suppl. 6, 169 (1968)). At our incident energies of about 1 GeV/nucl., the centre of mass energy of a *single* nucleon-nucleon scattering system is too low to allow for such emission. However, final state interactions of cascade nucleons is a possibility.

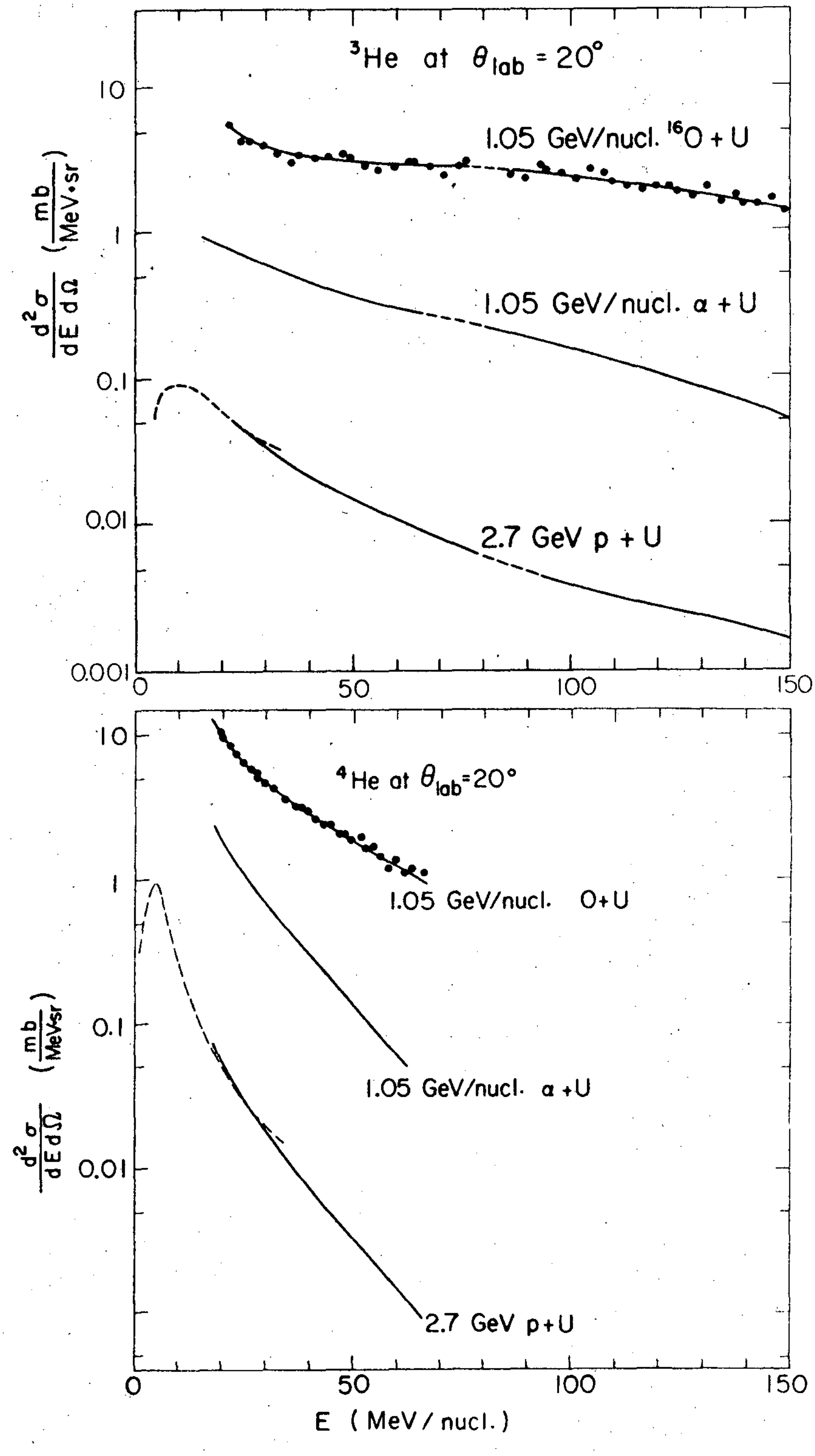
FIGURE CAPTIONS

Fig. 1. Comparison of ^{3}He (upper part) and ^{4}He (lower part) spectra at 20° (lab) obtained upon bombardment of a uranium target with protons of 2.7 GeV, α particles and ^{16}O ions with 1.05 GeV/nucl. The data points are shown for the ^{16}O + U spectra. For p + U dashed curves are shown for the low energy evaporation spectra obtained previously (ref. 12).

Fig. 2. Double differential cross sections for ^{3}He (upper part) and ^{4}He (lower part) produced by ^{16}O of 1.05 GeV/nucl. on uranium as a function of laboratory angle. Data points are shown at 20° and 60° to indicate the statistical quality of the data.

Fig. 3. Differential cross sections per unit angle, $d\sigma/d\theta$, of ^{3}He fragments emitted in various energy domains between 20 and 150 MeV/nucl from ^{16}O + Ag at 1.05 GeV/nucl incident energy.

Fig. 4. Angular distributions of ^{3}He and ^{4}He fragments observed with ^{4}He and ^{16}O projectiles on Ag and U targets.



^{3}He at θ_{lab} = 20°
1.05 GeV/nucl. ^{16}O + U
1.05 GeV/nucl. α + U
2.7 GeV p + U
$\frac{d^2\sigma}{dE\,d\Omega}$ $\left(\frac{mb}{MeV\cdot sr}\right)$
10
1
0.1
0.01
0.001
0
50
100
150
^{4}He at θ_{lab}=20°
1.05 GeV/nucl. O+U
1.05 GeV/nucl. α +U
2.7 GeV p+U
E (MeV / nucl.)
XBL759-3896

Fig. 1

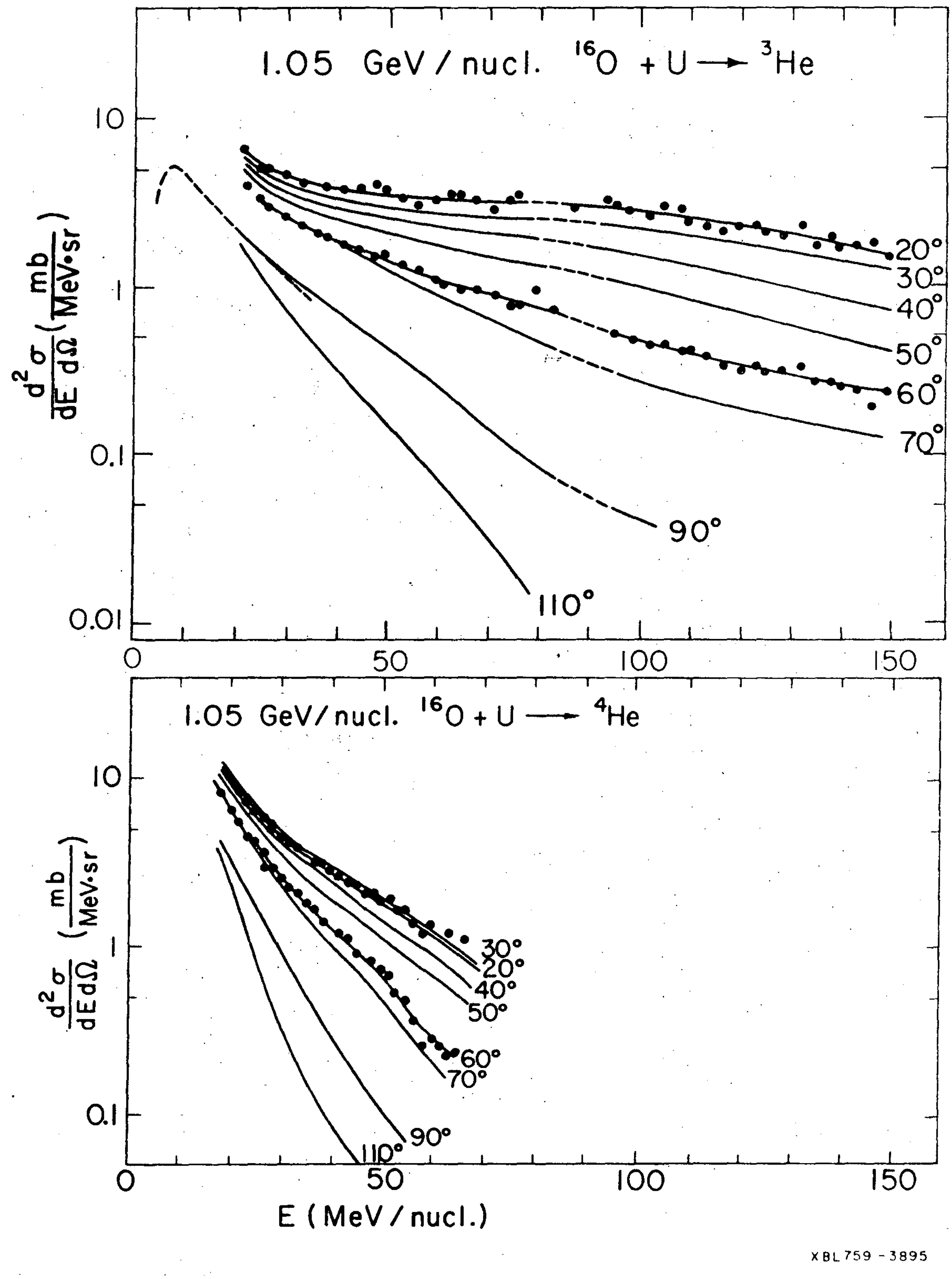
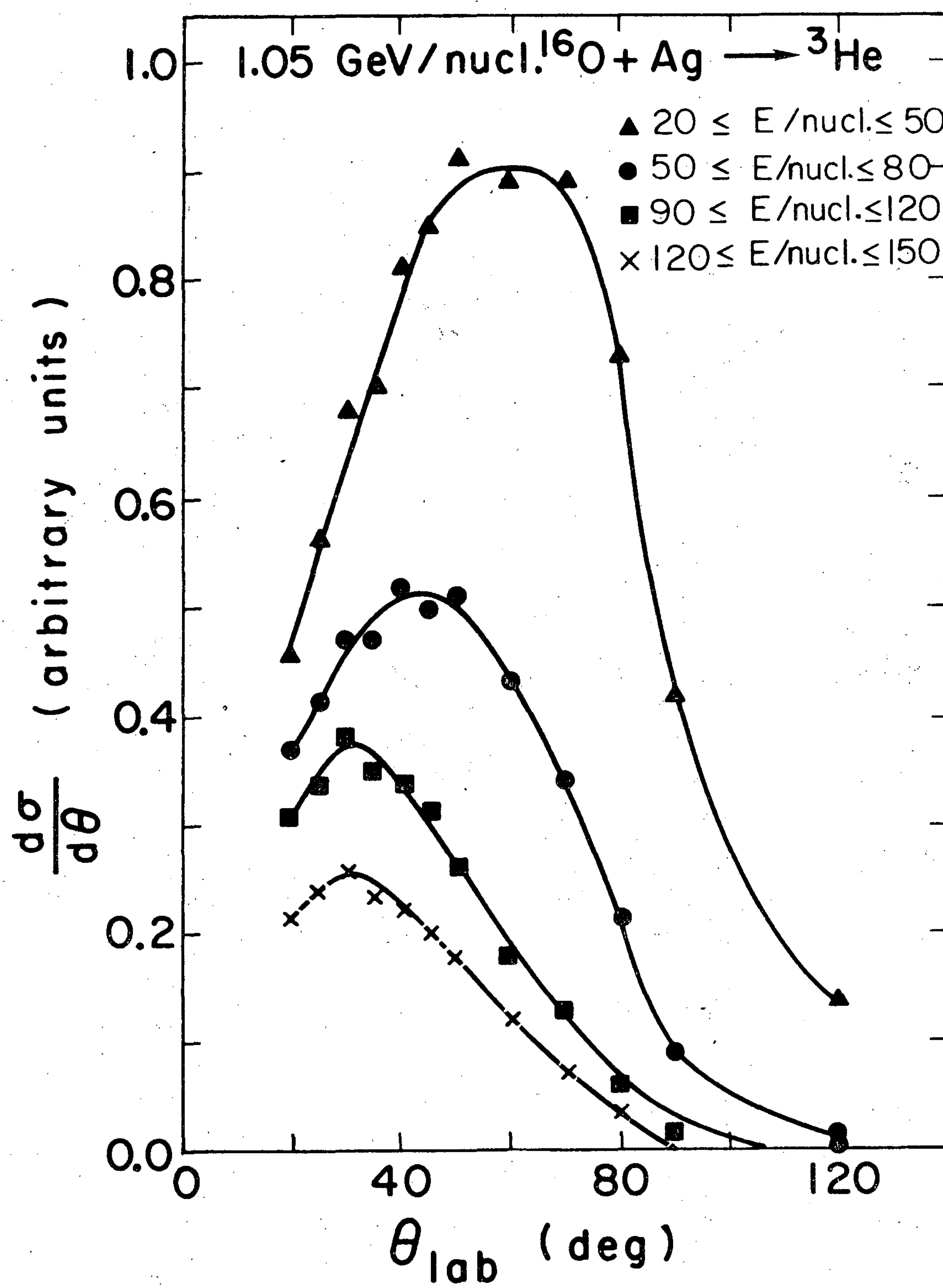
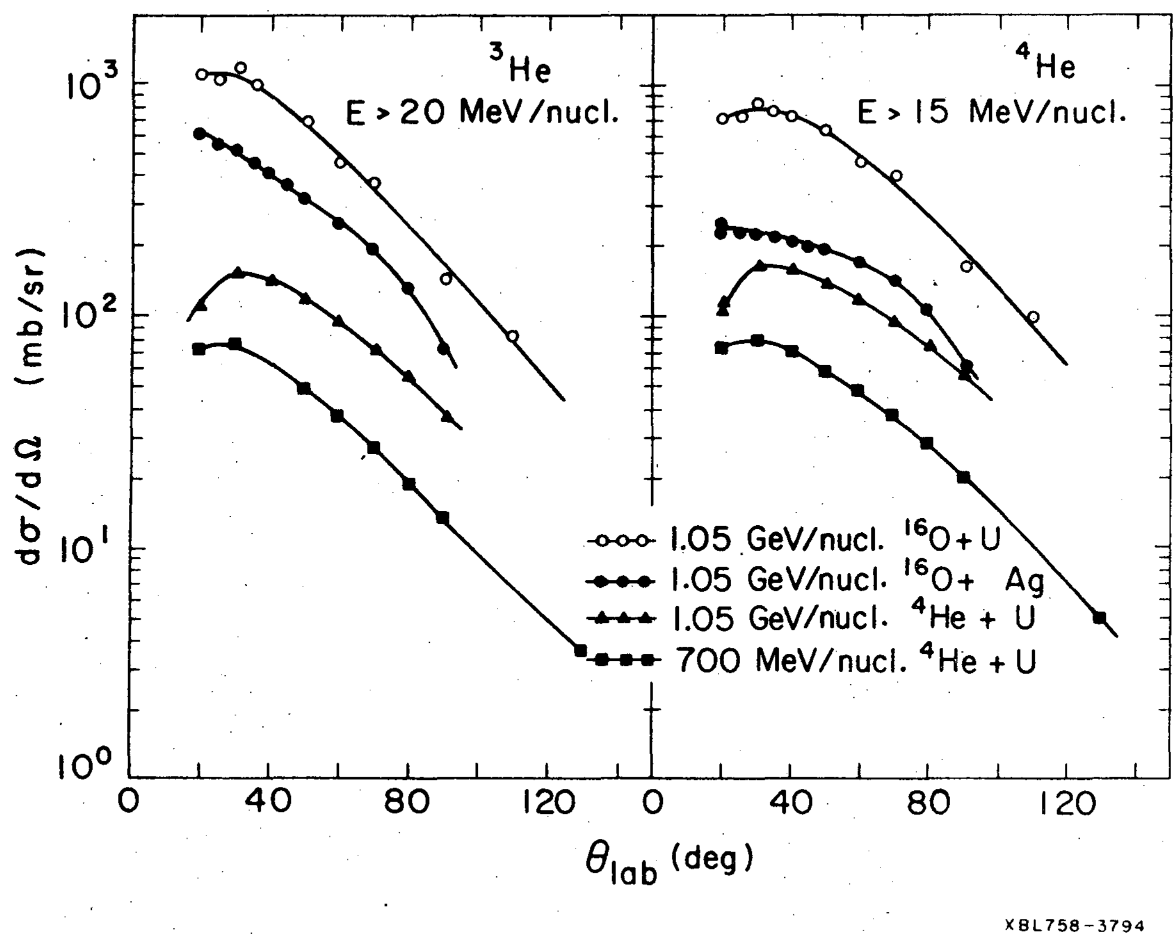

1.05 GeV / nucl. $^{16}O + U \rightarrow {}^3He$
$\frac{d^2\sigma}{dE\,d\Omega}\left(\frac{mb}{MeV \cdot sr}\right)$
10
1
0.1
0.01
0
50
100
150
20°
30°
40°
50°
60°
70°
90°
110°
1.05 GeV/nucl. $^{16}O + U \rightarrow {}^4He$
$\frac{d^2\sigma}{dE\,d\Omega}\left(\frac{mb}{MeV \cdot sr}\right)$
10
1
0.1
0
50
100
150
30°
20°
40°
50°
60°
70°
90°
110°
E (MeV / nucl.)
XBL 759 -3895

Fig. 2



XBL758-3792

Fig. 3



³He
E > 20 MeV/nucl.
⁴He
E > 15 MeV/nucl.
1.05 GeV/nucl. ¹⁶O + U
1.05 GeV/nucl. ¹⁶O + Ag
1.05 GeV/nucl. ⁴He + U
700 MeV/nucl. ⁴He + U
dσ/dΩ (mb/sr)
θlab (deg)
XBL758-3794

Fig. 4

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