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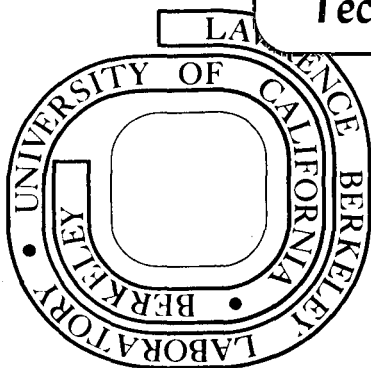
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A SEARCH FOR ANOMALOUS DENSITY EFFECTS IN CENTRAL COLLISIONS OF
RELATIVISTIC HEAVY IONS

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ABSTRACT

Single particle inclusive spectra and the associated multiplicity were obtained with a magnetic spectrometer and an azimuthal array of 30 Čerenkov counters from collisions of 1.8 GeV/nucleon ^{40}Ar on Be and Cu targets. No anomalous structure is seen in the spectra obtained with the spectrometer for various multiplicity requirements. The single particle inclusive differential cross sections are qualitatively predicted by the diffuse firestreak model.

Central (small impact parameter) collisions between high energy heavy ions have generated much interest recently. In such collisions one may hope to study nuclear matter at high densities and temperatures where exotic effects such as shock waves^{1,2} or density isomers²⁻⁹ may occur. A possible experimental signature for central collisions is the emission of a large multiplicity of fragments.

We have conducted an experimental study to develop selection criteria for central collisions and to examine these collisions for evidence of anomalous density effects. A movable magnetic spectrometer (Fig. 1) has been used to measure the production of light fragments (p, d, t, ³He, ⁴He) from collisions of a heavy projectile (⁴⁰Ar) on light (Be) and heavier (Cu) targets at 1.8 GeV/nucleon, the highest available bombarding energy (for ⁴⁰Ar) at the Bevalac. Data were taken at nearly all laboratory angles between 3.5° and 15.2° and at all rigidities between 1.5 and 7.5 GeV/c-Z. The momentum, the scattering angles θ and ϕ , the charge and the mass were measured for each particle detected by the spectrometer.

The rapidities of the detected particles extend to regions midway between those of the beam and the target. The momentum transferred to these fragments is typically much larger than the Fermi momentum. The present work extends projectile fragmentation data to higher momentum transfers than the previous work at 0.10 and 2.50.¹¹

An array of 30 lucite Čerenkov detectors (see Fig. 1) was used to measure the multiplicity distribution of fast charged particles associated with each particle detected by the spectrometer. This array had a θ_{Lab} acceptance of 40-120° or 50-160° which was selected

by varying the target-to-detector distance. The Čerenkov detectors have a velocity threshold of $\beta \geq 0.7$ (about half of the beam rapidity) and are in the form of azimuthal segments covering all of the azimuthal coordinate not occupied by the spectrometer acceptance. The kinematics of the reaction ensure that the multiplicity array accepts a large fraction of the fragments from the projectile which have received momentum transfers greater than the Fermi momentum.

We present in Fig. 2 the results for the production of hydrogen isotopes for $^{40}\text{Ar} + \text{Cu}$ and $^{40}\text{Ar} + \text{Be}$. The invariant inclusive cross section is plotted as a function of the laboratory momentum for $\theta_{\text{Lab}} = 5, 12$ and 14.7° . The data presented here are a fraction of the complete data sample which includes measurements at other angles between 4 and 14.7° . In all cases, the uncertainties are dominated by counting statistics, although the error bars shown in Fig. 2 include contributions from uncertainties in the computer live time, the chamber efficiencies, the number of target atoms, the beam flux, and the spectrometer acceptance.

At small laboratory angles (5°) the fragment distributions peak near β_p , the projectile velocity. The energy of the fragments in this peak corresponds to about 25 MeV/nucleon in the projectile rest frame. No peak is observed at larger laboratory angles (above 12°) where the minimum projectile rest frame kinetic energy is 150 MeV/nucleon.

The curves shown in Fig. 2 are predictions from the diffuse firestreak model.^{12,13} In this model, the projectile and the target are divided into tubes. At a given impact parameter, the overlapping projectile and target tubes undergo a completely inelastic one

dimensional collision along the beam direction. The resulting composite systems of "firestreaks" decay thermodynamically after expanding to a freeze out density ρ_0 . The calculations were done for $\rho_0 = 0.12 \text{ fm}^{-3}$, normal nuclear density being about 0.17 fm^{-3} . A description of these model calculations can be found in Ref. 13. Myers¹² has shown that by using diffuse nuclear matter distributions contributions from very large impact parameter (peripheral) collisions are included. In the model, the contributions from peripheral collisions dominate at rapidities near those of the beam and the target. The model at least qualitatively predicts the shape and magnitude of the data. The agreement is worse at the lower fragment momenta (see Fig. 2) and at smaller laboratory angles, where the predictions overestimate the measured cross sections.

The target dependence of the inclusive cross section W is plotted in Fig. 3 as the ratio $R_a = W(^{40}\text{Ar} + \text{Cu} \rightarrow a + X)/W(^{40}\text{Ar} + \text{Be} \rightarrow a + X)$, where a is either p , d or t , and X is anything. The dashed vertical lines in Fig. 3 indicate the beam rapidity Y_B , and the rapidity midway between the beam and the target, $Y_B/2$. The solid horizontal lines indicate the expected values of R_a if the cross section depends on the target periphery ($A_T^{1/3}$), the target area ($A_T^{2/3}$), or the target volume (A_T), where A_T is the number of nucleons in the target. At rapidities near $Y_B/2$, the deuteron data show a clear trend toward volume dependence for the target. This lends some support to the idea that particles emitted in this rapidity region are from central collisions.

We have examined the number distributions of particles in the multiplicity array for different spectrometer triggering conditions. To within statistical uncertainties, the average multiplicity is independent of both the type and the momentum of the fragment detected in the spectrometer.

As a test for possible correlations between a particular multiplicity requirement M and the inclusive cross section, W , we have studied the ratio $r = W_M(\theta_L, Y_L)/W(\theta_L, Y_L)$ as a function of the laboratory angle θ_L and rapidity Y_L . The quantity W_M is the inclusive cross section for those events satisfying M , and W is the inclusive cross section without any multiplicity requirement. Figure 4 shows r for protons, deuterons, and tritons as a function of rapidity at $\theta_L = 12^\circ$ for ^{40}Ar on a Be target. The multiplicity requirement is that at least seven fragments are detected by the Cerenkov detectors. According to the model of Stocker et al.,³ the fragments from a shock wave in the projectile nucleus (^{40}Ar) would peak at rapidities indicated by the shaded region. The absence of a peak in this ratio can be interpreted as evidence against the existence of a shock waves. This conclusion agrees with the results of Jacobson, et al.¹⁴ and Heckman, et al.¹ The ratio r was also examined for cases (1) requiring at least 2 particles detected in each of the four azimuthal quadrants and (2) requiring hits in 10 or more counters. For all cases, no statistically significant variation of r with fragment type or momentum is seen at a given angle.

We have, however, found that the ratio r increases with angle. As shown in Table 1, $\bar{r}$ (for $M \geq 7$ and averaged over momentum) increases by almost a factor of 2 as θ_L increases from 5° to 14.7° .

The multiplicity associated with the fragment detected in the spectrometer has only a small dependence on the target nucleus. At 5° , $\bar{r}(\text{Cu})/\bar{r}(\text{Be}) = 1.27 \pm 0.16$ and at 14.7° , this ratio increases to 1.40 ± 0.19 . It should be noted that at $\theta_L = 5^\circ$ the multiplicity counters acceptance is $4\text{--}12^\circ$, and at $\theta_L = 12$ or 14.7° it is $5\text{--}16^\circ$.

In summary, there is no evidence for anomalous density effects in our data. The multiplicities observed in the Čerenkov counters increase with angle but are independent of the type and the momentum of the fragment detected by the spectrometer. The weak target dependence of the ratio $\bar{r}$ indicates that the fragments detected by the Čerenkov counters come predominantly from the Argon projectile. It is possible that the multiplicity array in its present configuration is not restrictive enough in selecting central collisions. The data in Fig. 3 suggest that restricting the rapidity acceptance of the multiplicity counters to the region near $Y_B/2$ might make them more sensitive to central collisions. The overestimate of the cross section at low momenta (rapidities) by the diffuse firestreak model might be due to the assumption that the target and the projectile tubes undergo completely inelastic collisions. It has been suggested¹⁶ that at such a high bombarding energy, the target and the projectile material do not merge. This could severely limit the densities of nuclear matter achievable in relativistic heavy ion collisions.

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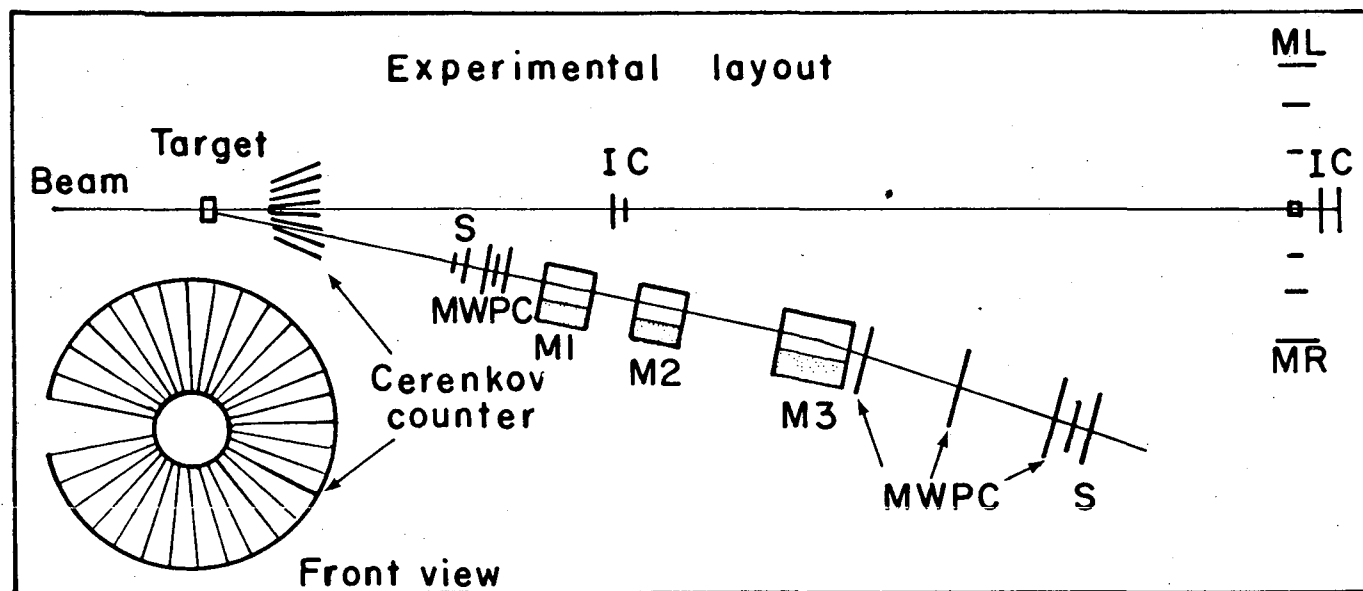
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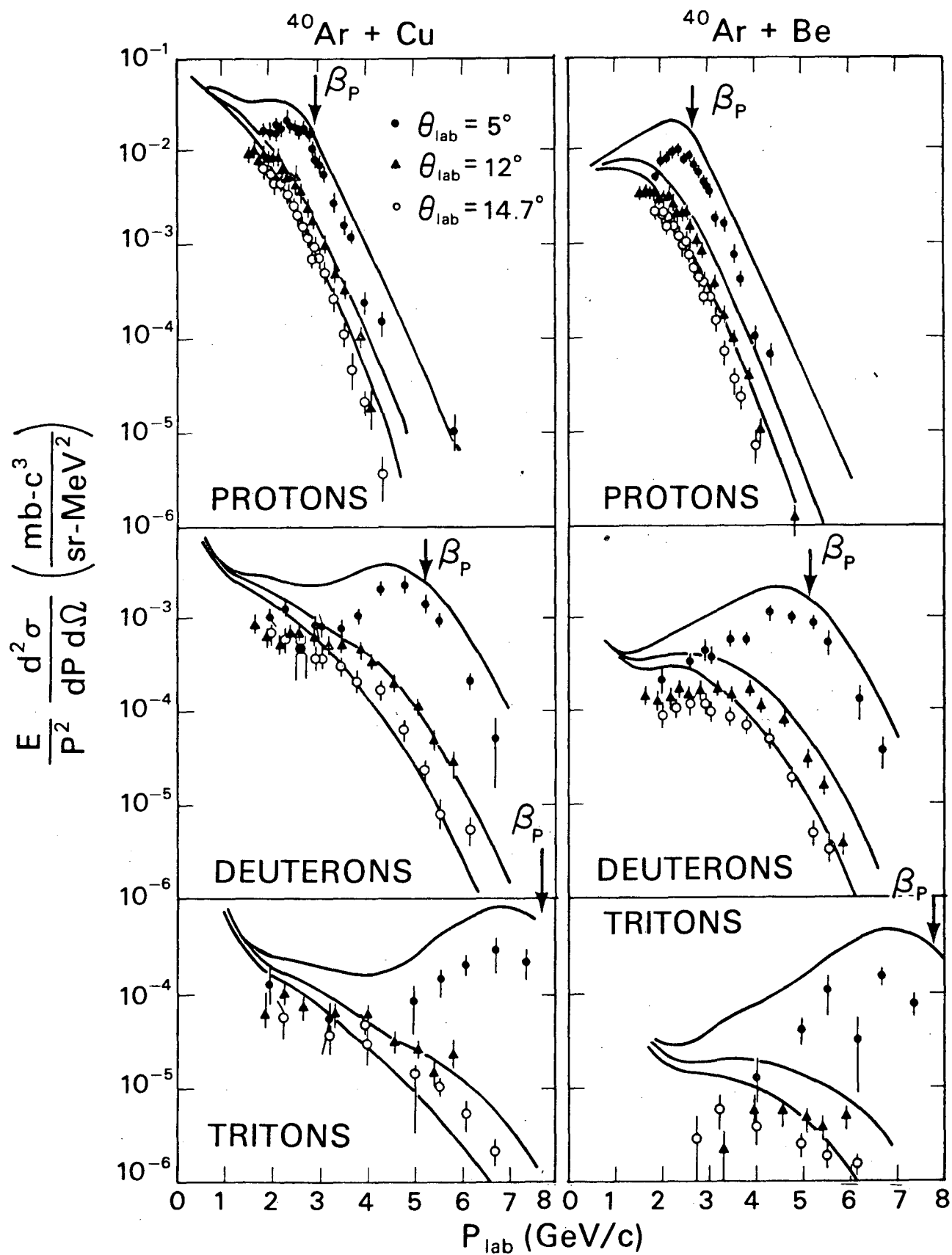
FIGURE CAPTIONS

- Fig. 1. The experimental layout shows the spectrometer consisting of 4 scintillator detectors (S), 6 multi wire proportional chambers (MWPC) and 3 bending magnets (M). The beam flux is monitored by 4 Ion Chambers (IC) and two scattering telescopes (ML and MR). The 30 azimuthal Cerenkov counters downstream from the target measure the multiplicity.
- Fig. 2. The invariant inclusive cross section $E/p^2 d^2\sigma/dp d\Omega$ for producing hydrogen isotopes at $\theta_{\text{Lab}} = 5, 12$ and 14.7° is plotted as a function of laboratory momentum for $^{40}\text{Ar} + \text{Cu}$ and $^{40}\text{Ar} + \text{Be}$. The beam velocity is indicated by β_p for the three different isotopes. Only statistical errors are shown. The curves are predictions from the diffuse firestreak model.
- Fig. 3. The target dependence of the inclusive cross section W is shown by plotting the ratio $R_a = W(\text{Ar} + \text{Cu})/W(\text{Ar} + \text{Be})$ as a function of rapidity. The horizontal lines indicate the peripheral $(A_T)^{1/3}$, the area $(A_T)^{2/3}$, and volume (A_T) target dependence. The dashed vertical lines indicate the beam rapidity Y_B and $Y_B/2$.
- Fig. 4. The ratio r is plotted as a function of rapidity Y_L for hydrogen isotopes detected at 12° for $^{40}\text{Ar} + \text{Be}$. The quantity r is defined as $r = W_{m>7}(\theta_L, Y_L)/W(\theta_L, Y_L)$ where m is the observed multiplicity and W is the inclusive cross-section. The shaded regions indicate where the shock wave peak should occur according to Ref. 3.



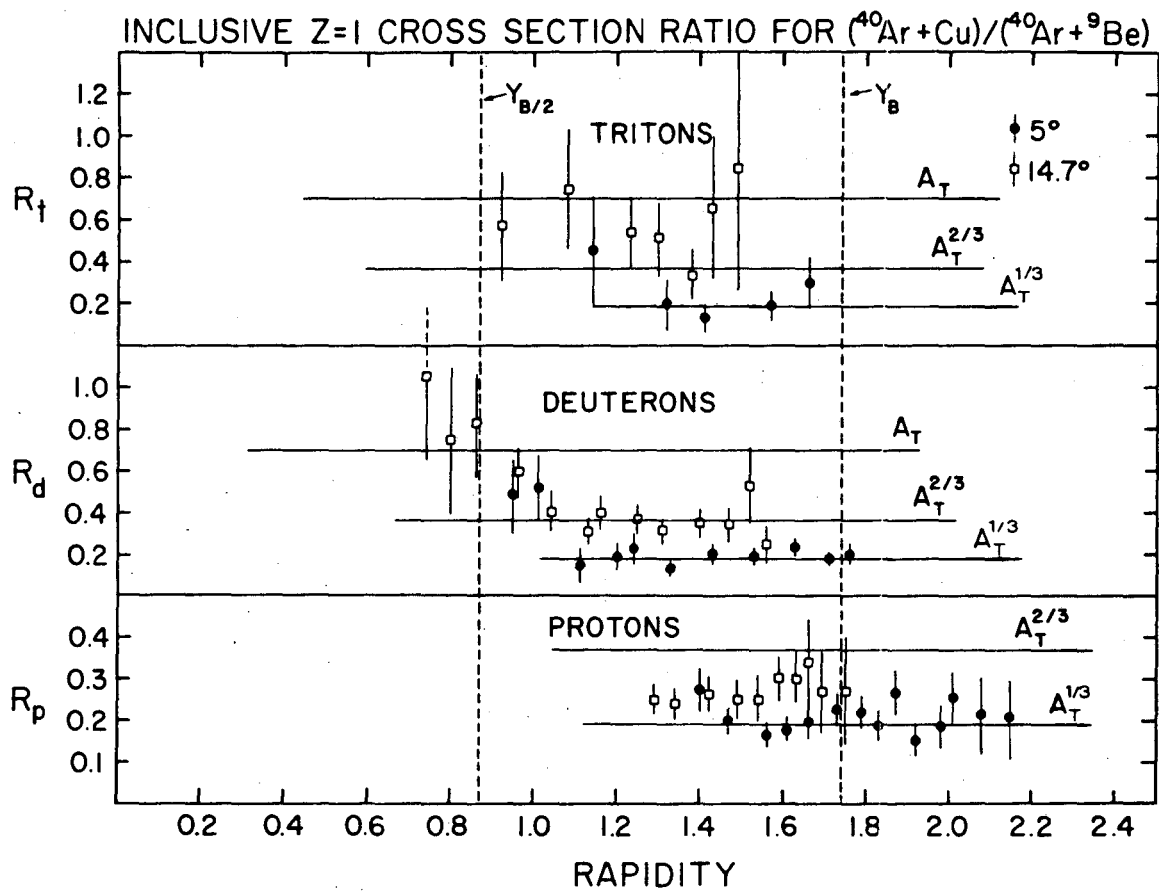
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Fig. 1



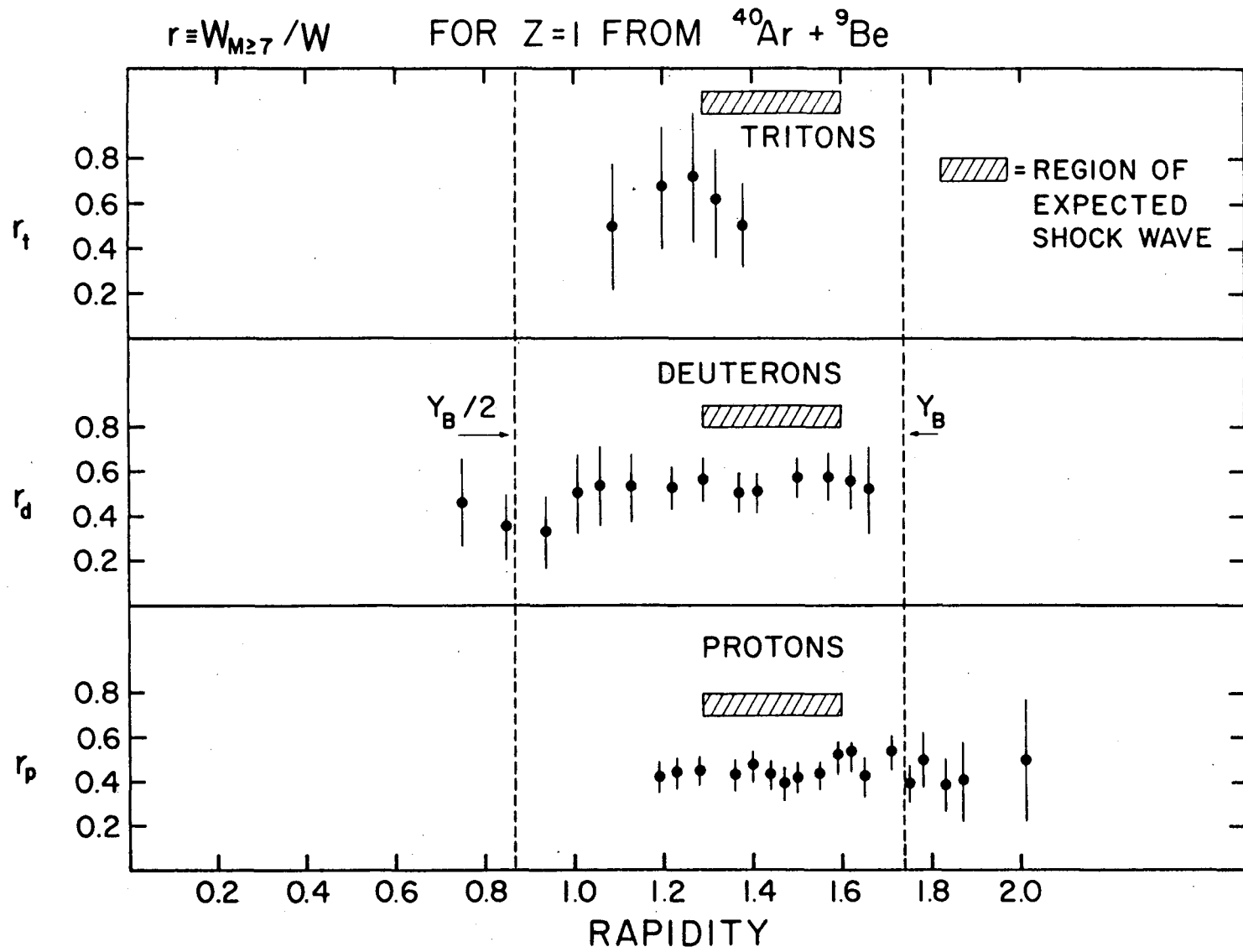
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Fig. 2



XBL 778-1632

Fig. 3



XBL 782-7249

Fig. 4

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