DETERMINATION OF PRIMARY ENERGY IN NUCLEUS-NUCLEUS COLLISIONS AND THE HIGH p_T TAIL OF α-PARTICLES

P. S. Freier and T. W. Atwater
School of Physics and Astronomy, University of Minnesota
Minneapolis, Minnesota 55455

Abstract. A determination of primary energy is required in order to study the energy dependence of meson multiplicity in A-A collisions in cosmic rays. Various procedures which estimate the energy of a primary nucleus from its interaction have been investigated. We have used an average of two methods, one using the pions and wounded protons and the other using spectator protons and α-particles. The high p_T tail observed for $Z = 2$ fragments requires a modification of the latter method.

1. Introduction. From accelerator studies of 1.7 and 3.7 GeV/amu of A-emulsion inelastic collisions, the distribution in p_T for projectile fragments has been measured for ^{12}C, ^{14}N, ^{16}O and ^{56}Fe beams.[1-4] Although the distribution in p_T for $Z = 1$ fragments is consistent with a Gaussian-like distribution

$$\frac{dN}{dp_T} = \frac{p_T}{\sigma^2} \exp\left(-p_T{}^2/2\sigma^2\right) \qquad (1)$$

with $\sigma = 100$ MeV/c ($\langle p_T \rangle = 125$ MeV/c),[3] for fragments of $Z \geqq 2$ there is a marked deviation from this shape due to the presence of a tail of large momentum transfers. This high p_T tail results in $\langle p_T \rangle$ being significantly larger than the $\langle p_T \rangle$ expected from eq. (1). For $Z = 2$ fragments from ^{12}C, $\langle p_T \rangle = 241 \pm 8$ MeV/c,[1] and from ^{56}Fe, $\langle p_T \rangle = 370 \pm 10$ MeV/c.[3] $\langle p_T \rangle$ seems to depend only weakly on target A, ($\sim A^{0.05}$) but the dependence on projectile A is more pronounced ($\sim A^{0.25}$).[3] This increase in $\langle p_T \rangle$ is mainly due to the enhancement of the high p_T tail with A_p of the projectile. We shall show that the high p_T tail is also enhanced as the energy of the projectile is increased.

2. Measurements on Beam Projectiles. We have analyzed 105 ^{55}Mn-emulsion interactions at $\langle E \rangle = 1.69 \pm 0.3$ GeV/amu, measuring the emission angles of fragments, α-particles, protons, and mesons. The angular distribution of α-particles is shown in Fig. 1. The transverse momentum, p_T, is calculated from the angle assuming ^4_2He is emitted at the same momentum per nucleon, p_o, as the projectile had at the interaction:

$$p_T = 4\, p_o \sin \Theta \qquad (2)$$

The peak in the angular distribution corresponds to p_T (peak) = 240 MeV/c, while $\langle p_T \rangle = 356 \pm 20$ MeV/c. This $\langle p_T \rangle$ value agrees very well with the value 370±10 MeV/c measured by Chernov et al.[3] for α-particles from ^{56}Fe at 1.7 GeV/amu.

The emission angles of α-particles from ^{179}Au-emulsion interactions at 0.5 - 1.0 GeV/amu are also shown in Fig. 1. (The energy at each interaction was calculated by correcting for ionization loss of the

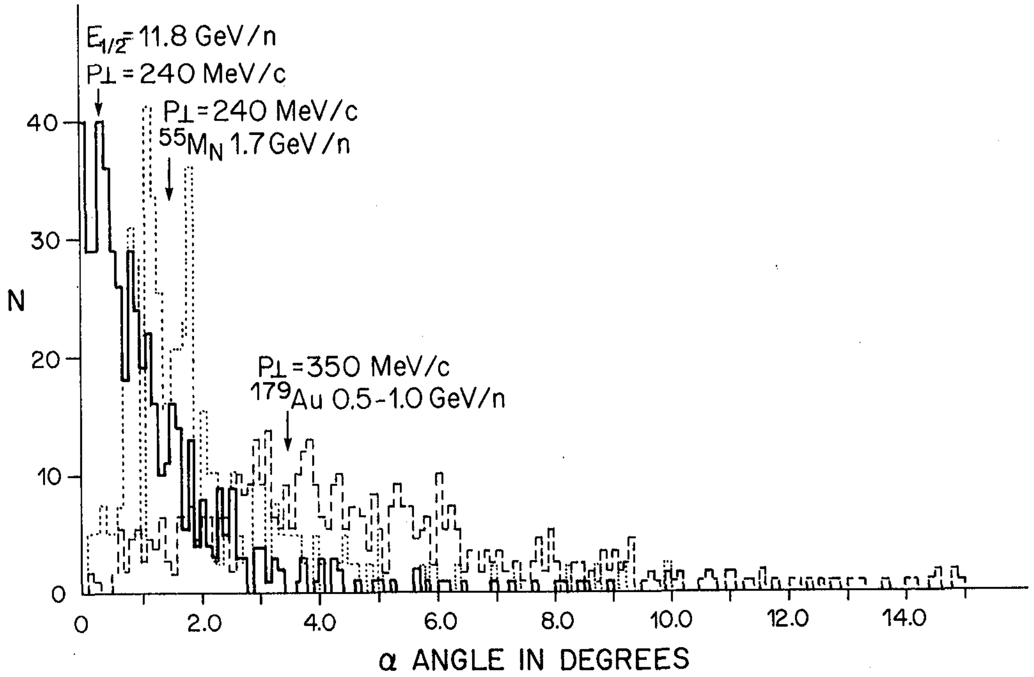

Fig. 1. Angular distributions of α-particles from A-emulsion interactions. ..... Mn at 1.7 GeV/amu; --- Au at 0.5-1.0 GeV/amu; —— cosmic rays, Z = 6-26 at E ≧ 7.5, $E_{1/2}$ = 11.8 GeV/amu. The arrows show the angles corresponding to the measured p_T(peak) for Mn and Au and to p_T(peak) = 240 MeV/c at the median energy for cosmic rays.

projectile.) There is a marked shift of the angular distribution to larger angles due both to the lower primary energy but also to an increase in p_T(peak) and an enhanced tail of high momentum transfers. The peak corresponds to p_T = 350 MeV/c but $\langle p_T \rangle$ = 520 MeV/c.

We have used the angles of emitted mesons, protons, and α-particles from ^{55}Mn-emulsion interactions to calculate the energy of the Mn projectile using two different methods: one uses the participant protons (WP) and produced mesons (M), and the second uses the spectator protons (SP) and α-particles. Paper HE 1.4-10 of these proceedings discusses the first method and the separation of spectator and participant protons.[5] This paper discusses the second method and what adjustments are required in applying it to higher energy cosmic ray projectiles.

Providing p_T is approximately independent of energy, we can estimate the primary energy from

$$P_{primary} = \frac{p_{T_{SP}}^{eff} \sum_i^{N_{SP}} \frac{1}{\sin \Theta_i} + \frac{1}{4}\, p_{T_\alpha}^{eff} \sum_i^{N_\alpha} \frac{1}{\sin \Theta_i}}{N_{SP} + N_\alpha} \qquad (3)$$

where $P_{primary}$ is the momentum per nucleon and the p_T are effective values of spectator and α-particle transverse momentum given in the

Table. This estimate of energy (eq. 3) will be dominated by spectator protons since $\langle N_{SP} \rangle \sim 4 \langle N_\alpha \rangle$. The Table shows the peak values of p_T for α-particles and spectator protons measured in the interactions of the ^{55}Mn beam. The p_T used for wounded protons and mesons (discussed in Paper HE 1.4-10) are also shown in the Table. The "beam" average and median energies are shown in columns 2 and 3 of the Table and can be compared to the calculated energies in columns 8 and 9. The calculated energies are simply averaged from the spectator and participant energy determinations. Figure 2 shows this average energy for the Mn beam. Some 70% of the particles have measured energies within E ± E/2.

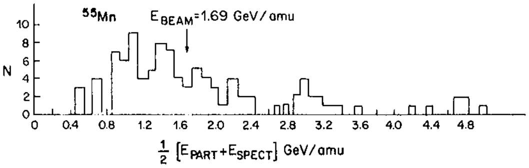

Fig. 2. The distribution in measured energy, 1/2[E (participant) + E (spectator)], for a 1.69 GeV/amu Mn beam.

Table. Effective p_T used in Energy Determination

Beam			p_T^{eff} (MeV/c)				Energy (GeV/amu)		Tail/Peak
$\bar{Z}$	⟨E⟩	$E_{1/2}$	SP	α	WP	M	⟨E⟩	$E_{1/2}$	
25.0	1.69	1.68	101	232	575	175	2.03	1.51	0.020
13.0	5.50	3.00	106	232	438	179	5.67	2.82	0.084
14.5	19.60	11.80	255	680	691	384	19.90	12.40	0.218

3. Energy Measurements on Cosmic Ray Nuclei. Using the same techiques as used for Mn, we determined the energy of each cosmic ray primary from its interaction. For the 1000 nuclei measured over Texas where E ≧ 1.7 GeV/amu, the p_T values determined from the Mn beam gave reasonable measurement of energy (see Table). However, for the 500 nuclei measured over India where E ≧ 7.5 GeV/amu, the energies determined from the spectators using the same values of p_T were far too low. A remeasurement of many of the angles showed they were correct to within ± 0.1°. The observed peak in the α-particle angular distribution is consistent with the beam value p_T(peak) = 240 MeV/c and the median cosmic ray energy, $E_{1/2}$ = 11.8 GeV/amu (see Fig. 1). However, the tail to peak ratio, where the cut is defined as six times the peak angle, is much larger in India (see Table). The result is too many low energy events. (For a higher angle cut there were no particles in the Mn tail; the tail to peak ratio for Au is 0.005.)

The effective p_T for the cosmic rays given in the Table were determined by the requirement that the calculated energies fit the cosmic ray energy spectrum as closely as possible. Figure 3 shows the resulting energy spectrum of the 500 particles measured in India compared to a power law in total energy of $E^{-1.7}$. The energy measured from 1000 particles at Texas (E > 1.7 GeV/amu) fits equally well.

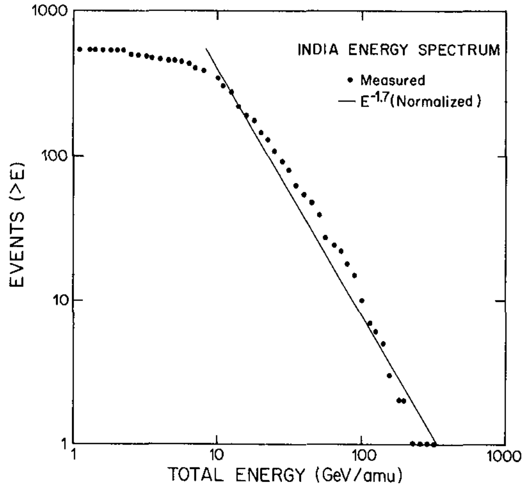

Fig. 3. The integral energy spectrum measured by 1/2 [E_{part} + E_{spect}] compared to the accepted cosmic ray spectrum, $J > E = kE^{-1.7}$.

4. Conclusions. Calculation of energies of primary cosmic rays using a method assuming constant p_T of fragments fits the known energy spectrum for a low energy data set (E > 1.7 GeV/amu). The required effective p_T for cosmic rays > 7.5 GeV/amu are high. The high p_T^{eff} for α-particles can be attributed to the high p_T tail. Since p_T^{eff} for protons must be increased by about the same factor to fit the cosmic ray spectrum, it appears that a high p_T tail must also be present for spectator protons. The high p_T tail increases with energy.

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