MESON MULTIPLICITY IN NUCLEUS-NUCLEUS COLLISIONS ABOVE 4 GeV/amu

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

Abstract. Dependence of meson multiplicity on energy for 1486 cosmic ray nucleus-emulsion nucleus interactions is examined. Comparison is made to predictions of the Multi-Chain Model.

1. Introduction. In the near future, relativistic heavy ion accelerators will for the first time probe energies larger than 4 GeV/amu with heavy nuclei. Cosmic rays are currently the only available "beam" at such energies. To date little data has appeared which utilizes the cosmic rays in an unbiased manner to measure the meson multiplicity as a function of energy. This work presents data on the multiplicity per interacting projectile proton up to 100 GeV/amu.

2. Description of Data. Nuclear emulsions were exposed on three balloon flights: two each at cutoff energies E > 1.7 GeV/amu (over Texas) and one at E > 7.5 GeV/amu (over India). 1486 events have been completely analyzed, including angle measurements of mesons, protons, alphas and heavier projectile fragments. Projectile charge ranged from $Z_p = 6$ to 30, with average $Z_p = 13.5$. The number of charged mesons produced in one interaction is defined by charge conservation:

$$n_{\pi\pm} = n_s - (Z_p - \sum_i Z_i)$$

where n_s is the number of singly-charged particles with ionization < 1.4 I_{min}, Z_p is projectile charge, and Z_i denotes projectile fragments with $Z \geq 2$. Identified lower energy mesons are also included. Error in determining $n_{\pi\pm}$ is less than one per event. Angle measurements, used to determine energy of the primary, have an estimated error of 0.1°. The number of wounded (inelastically interacting) projectile protons Q_p is estimated on an event-by-event basis, utilizing the fact that in many of the events projectile and central regions of the pseudorapidity histograms are well separated. Target diagrams, i.e., cross-sections of the secondary beam 1000 μ downstream from the interactions, are also used. While this method of determining Q_p is clearly approximate, it is justified by the fact that rough agreement is obtained with Glauber-type calculations of $\langle Q_p \rangle$.

Data taken from emulsions exposed to the 1.75 GeV/amu ^{55}Mn beam at the Bevalac were also used both to calibrate the energy determination and to supplement the $n_{\pi\pm}$ data.

It should be emphasized that all of the data was taken in an unbiased manner so as to detect all inelastic interactions. Defining the latter as those collisions in which the projectile charge is changed, it can be said that essentially all of the inelastic interactions in "along-the-track" scanning were found and measured. Due to time considerations many of the events with zero meson multiplicity were not completely analyzed for angles of nuclear fragments, most of which were in the lower energy (Texas) part of the data. A correction factor based on events that were completely measured has been applied to correct for this. Thus the measured values should represent the true meson multiplicity for inelastic interactions.

The energy per nucleon of the primary cosmic ray nucleus is measured by utilizing the angular distribution of all charged secondaries. Several methods are employed, all of which depend on the relative constancy of the transverse momentum. One method uses wounded protons and mesons, as suggested by Varyukhin et al.[1] The primary momentum per nucleon is given by

$$P_{prim}(\mathrm{GeV/amu}) = \frac{\left(\frac{3}{2} f_{\pi}\langle p_{\perp}\rangle_{\pi} + \frac{A}{z} f_{Q}\langle p_{\perp}\rangle_{Q_p}\right) \sum_{i}^{n_{\pi}+Q_p} \frac{1}{\sin \Theta_i}}{Q_p}$$

where $n_{\pi\pm}(Q_p)$ is the number of charged mesons (wounded projectile protons) in an event, $f_{\pi}(f_Q)$ is the relative number fraction, and the factor 3/2(A/Z) accounts for π°s (neutrons).[2] The factor $1/Q_p$ is used because all of the momentum of the wounded protons and mesons after the interaction must arise form the Q_p wounded protons. For the first try at computing P_{prim}, values of $\langle p_{\perp}\rangle$ measured at accelerator energies were used, viz.: $\langle p_{\perp}\rangle_{\pi}$ = 235 (320) MeV/c for the Texas (India) data set;[3] $\langle p_{\perp}\rangle_{Q_p}$ = 575 MeV/c[4] for both data sets. The resultant energy distribution was then compared to the known cosmic ray energy spectrum, $N(>E) \sim E^{-1.7}$ (E = total energy/amu). The values of $\langle p_{\perp}\rangle$ are subsequently modified by a suitable factor so that agreement with the known spectrum is as close as possible. This factor is 0.76 for the Texas data set and 1.20 for the India data set. Primary energy is also measured using the spectator particles, i.e., protons and alphas. This is detailed in a separate paper.[5] The energies obtained by these two separate methods are simply averaged. The resultant energy distribution is considered to order the events in energy. For a comparison of the result to the cosmic ray energy spectrum, see Ref. 5. The fit to the high energy part of the spectrum is fairly good, but at the low end there are too many (∿25%) events below the known cutoffs. A Monte Carlo simulation was performed assuming a Gaussian in energy with $\sigma \sim 0.5$ E, as seen in the Mn beam data. The result implies that many of the events below the cutoff may be due to the inherent spread in the measurement. However, when consolidating the data by binning the particles in energy, this does not matter, as long as the <u>ordering</u> in energy is correct. (For this reason also the precise values of $\langle p_{\perp}\rangle$ used are relatively unimportant.) The average energy of each bin is calculated using the number of events in the bin and the known energy spectrum.

<u>3. Model.</u> Comparison is made to the Multi-Chain Model (MCM) as formulated by Sumiyoshi,[6] which is essentially an independent particle picture utilizing Glauber theory concepts.[7] Input to MCM is the inelastic p-p cross-section σ_{pp}^{inel} and the p-p total charged multiplicity $\langle n_{ch}\rangle_{pp}$. Colliding nucleons are connected by chains which exchange energy. Equipartion of energy among chains is required. Cascade effects are roughly included by adding 1 to $\langle n_{ch}\rangle_{pp}$ for all collisions but the first for each wounded nucleon. Since the model predicts meson plus wounded proton multiplicity, in the model $\langle n_{ch}\rangle/\langle Q_p\rangle - 1$ should be compared to the data. The model is not claimed to be valid below 10 GeV/amu.[8]

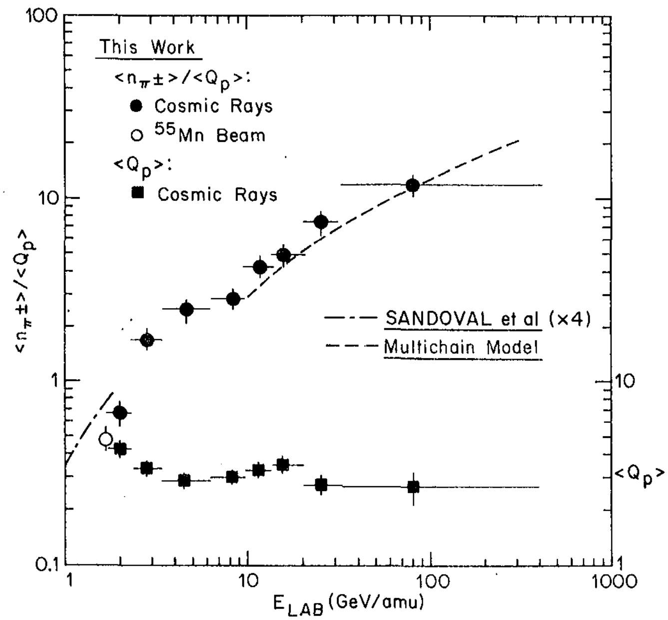

Fig. 1. Meson multiplicity per wounded projectile proton $<n_{\pi\pm}>/<Q_p>$ vs. energy for cosmic rays in emulsion. Shown also are: ^{55}Mn-emulsion point; streamer chamber data of Sandoval et al.,[9] multiplied by 4 to account for target protons and π^+s; Multi Chain Model prediction,[7] valid for E > 10 GeV/amu; and average wounded projectile protons vs. energy. Note large uncertainty in assigning energy value to highest energy point.

4. Results. Meson multiplicity per interacting projectile proton $<n_{\pi\pm}>/<Q_p>$ as a function of energy is shown in Fig. 1. Also shown is the ^{55}Mn-emulsion value at 1.69 GeV/amu. The experimental number of wounded projectile protons $<Q_p>$ is also included on the plot. It is seen that $<n_{\pi\pm}>/<Q_p>$ varies with energy approximately as $E^{0.7}$ above 4 GeV/amu. The data seem to follow the trend of the MCM prediction. Both the cosmic ray data and the Mn beam point fall below the Ar-KCl data of Sandoval et al.[9] For the cosmic ray data, this may partly be due to an overestimate of the number of wounded protons $<Q_p>$ at this energy (see Fig. 1). However, for the Mn case, this is not true since $<Q_p>$(expt) = 5.2 while $<Q_p>$(Glauber) = 5.0. According to Glauber theory $<Q_p>$ is only a weak function of energy, viz. < 3% variation from 2-100 GeV/amu. $<Q_p>$ (Glauber) = 3.1 for the average cosmic ray projectile on emulsion while $<Q_p>$ (expt) = 3.3 integrated over energy.

To show the spread in the data, Fig. 2 gives a scatter plot of the 482 events from the India flight (E > 7.5, E = 19.6, median E = 11.8 GeV/amu).

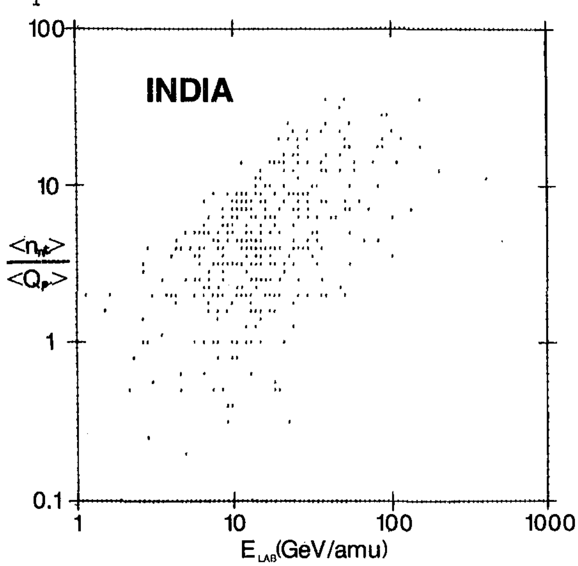

Fig. 2. Scatter plot of meson multiplicity per wounded projectile proton vs. energy for India flight data.

Table 1 shows the projectile charge dependence of the multiplicity per wounded projectile proton integrated over energy. Higher Z_p appears to give lower $\langle n_{\pi\pm}\rangle/\langle Q_p\rangle$. This can only partly be accounted for by the fluctuation in $\langle Q_p\rangle$ as shown in Table 1. As an aside, note that the value of $\langle n_{\pi\pm}\rangle/\langle Q_p\rangle$ for high Z_p (≥ 20, $\bar{Z} = 23.3$) in the lowest energy cosmic ray bin is very close to the value for the Mn beam (Z = 25), both showing internal consistency of the results and lending credibility to the cosmic ray energy determination.

Table 1. $\langle n_{\pi\pm}\rangle/\langle Q_p\rangle$ vs. Projectile Charge[a]

Flight	Projectile Z_p	Events	$\langle Q_p\rangle$ Expt	$\langle Q_p\rangle$ Glauber	$\langle n_{\pi\pm}\rangle/\langle Q_p\rangle$
Texas	6-9	412	2.2 ± 0.1	2.22	2.9 ± 0.3
(E>1.7 GeV/amu)	10-19	508	3.7 ± 0.2	3.13	1.9 ± 0.2
	20-26	332	4.4 ± 0.3	4.53	1.5 ± 0.2
India	6-9	141	2.4 ± 0.2	2.24	5.5 ± 0.7
(E>7.5 GeV/amu)	10-19	236	2.8 ± 0.2	3.17	5.7 ± 0.7
	20-26	142	5.5 ± 0.5	4.58	3.8 ± 0.6

[a]Values are corrected for unmeasured zero meson events.

5. Conclusion. For the first time a systematic unbiased study has been made of the meson multiplicity in relativistic heavy ion collisons from 2 to 100 GeV/amu. Multiplicity per wounded proton rises roughly as $E^{0.7}$ at E > 4 GeV/amu. Heavier projectiles show a somewhat lower multiplicity per wounded projectile proton than lighter ones do. The data roughly follows the Multi-Chain Model prediction.

6. Acknowledgements. We thank Mary Olson and Hilde Rahlenbeck for the careful measurements of interactions. We acknowledge useful conversations with J. Kapusta and L. Csernai. We thank J. Mevissen for computing assistance. This work was supported in part by NSF Grant PHY-8405852, NASA Grant NGR 24-005-050, and the University of Minnesota Computer Science Center.

References

[1] Varyukhin, V. V., et al. (1984), Phys. Scr. **29**, 37.
[2] Note that Ref. 1 uses the same $\langle p_\perp\rangle$ for both mesons and wounded protons.
[3] The value 235 MeV/c is taken from an average over nucleus-nucleus data for $\langle p_\perp\rangle_{\pi^-}$ at 4.5 GeV/c/amu measured by Anikina et al. (1983), JETP Lett. **36**, 331; the value 320 MeV/c was extrapolated from the latter value using the energy dependence of $\langle p_\perp\rangle$ from proton-proton data.
[4] This value was derived from a distribution in Agakishiev et al. (1983), Sov. J. Nucl. Phys. **38**, 90.
[5] Paper HE 1.3-1, these proceedings.
[6] Sumiyoshi, H. (1983), Phys. Lett. **131B**, 241.
[7] Glauber, R.J. (1959), Lectures in Theoretical Physics, ed. W.E. Brittin, **Vol. 1**, Springer, Berlin, p. 315.
[8] Kinoshita et al. (1981), Z. Phys. **C8**, 205.
[9] Sandoval et al. (1980), Phys. Rev. Lett. **45**, 874.