Multiple scattering of cosmic ray muons in the range 10-70 GeV/c

1972 J. Phys. A: Gen. Phys. 5 L102

(http://iopscience.iop.org/0022-3689/5/10/004)

J. Phys. A: Gen. Phys., Vol. 5, October 1972. Printed in Great Britain. © 1972.

LETTER TO THE EDITOR

Multiple scattering of cosmic ray muons in the range 10–70 GeV/*c*

C A AYRE, M A HAMDAN, C J HUME, B C NANDI,
M G THOMPSON, S C WELLS, M R WHALLEY and
A W WOLFENDALE
Physics Department, University of Durham, South Road, Durham City, UK

MS received 17 August 1972

Abstract. The new Durham spectrograph, MARS, has been used to study the Coulomb scattering of cosmic ray muons in iron in the momentum range 10–70 GeV/*c*. The observed root mean square lateral displacement agrees well with that predicted to within the statistical errors, which range from 2% at the lowest momentum to 17% at the highest momentum. Averaged over the whole momentum range the ratio of observed to expected root mean square scattering displacement is $1{\cdot}023 \pm 0{\cdot}019$.

An examination of the scattering of a particle is a standard technique for investigating the character of the interaction between the particle and matter. In the case of the muon, searches have been made over many years for the existence of an 'anomalous' interaction in addition to the well known Coulomb and weak interactions. There have been a number of claims for the discovery of anomalies but none has so far been substantiated. However, in view of the great importance of the subject (the reason for the existence of the muon is not clear if it is merely a 'heavy' electron) the search continues. Measurements with the MARS instrument (Ayre *et al* 1972) are enabling earlier precise studies of various processes to be extended to higher momenta and the present work relates to an analysis of multiple scattering.

In a previous work (Ayre *et al* 1971) it was pointed out that the determination of the trajectories of near-vertical muons in five horizontal detection layers (which alternate with four magnet blocks) allow not only the momenta of the particles to be determined but also other parameters as well. This possibility arises because only three coordinates are needed to determine the momentum. In the work of Ayre *et al*, the lateral displacements were examined and, by fitting a polynomial to each track, the momentum and an estimate of the rate of loss of momentum were determined for each particle. The combination of data from groups of particles of similar momenta enabled fairly precise measurements of the mean rate of total momentum loss to be made. In the present analysis, parabolic trajectories are fitted to the five points from the experimental data. The dispersion of the points about the trajectory is due to multiple scattering, that is Coulomb scattering in the absence of an anomalous interaction, errors of measurement arising primarily from the finite size of the neon flash tubes used in the detection layers, and systematic effects due to the lack of exact applicability of the parabolic path.

The analysis has been made by means of a computer simulation of muons through the spectrograph, the multiple scattering, momentum loss and magnetic bending being taken into account. By fitting a parabola to the five predicted coordinates, in the same manner as is done in practice, and measuring the dispersion around this parabola, the various effects are allowed for in an accurate fashion (with the exception of measurement errors).

The quantity determined for each trajectory is

$$\Delta^2 = \tfrac{1}{5} \sum_{1-5} \delta_i^2$$

where δ_i is the lateral displacement of the best fit trajectory and the measured track position at the *i*th level of the spectrograph. The basic data comprise measurements of Δ obtained in a preliminary series of observations with MARS using photographic recording.

The data are then collected together in muon momentum bins, typically of width 5 GeV/*c*, to produce distributions of Δ. Quantities of interest are the arithmetic mean $\overline{\Delta}$, and the RMS $\sqrt{\overline{\Delta^2}}$, for these distributions.

In the absence of anomalies,

$$\overline{\Delta^2} = \frac{G}{p^2} + \Delta_0{}^2$$

where G is a factor containing the geometry of the instrument and atomic constants which is a slowly varying function of momentum due to momentum loss and the inherent inaccuracy of the parabolic fit. $\Delta_0{}^2$ is the mean square displacement due to noise alone. Calculation shows that above 100 GeV/*c* the displacement is almost entirely due to noise and $\Delta_0{}^2$ has been derived from the measured values in this region. This value has then been subtracted from the observed values of $\overline{\Delta^2}$ at momenta below 70 GeV/*c* to give the corrected values, $\overline{\Delta_c{}^2}$. The uncertainty in $\Delta_0{}^2(\sim 6\%)$ has been allowed for when calculating the errors in the $\overline{\Delta_c{}^2}$ values. The same procedure has been adopted in calculating the arithmetic mean, that is replacing $\overline{\Delta^2}$ by $(\overline{\Delta})^2$ etc.

Turning to the problem of calculating the theoretical values of $\overline{\Delta_c{}^2}$ and $\overline{\Delta_c}$, the method of Cooper and Rainwater (1955) has been adopted. This method allows for finite nuclear size and electron cloud shielding in an accurate fashion. Calculations have been made for a single magnet block with the result that the scattering constant $K = 20{\cdot}80$ MeV/*c* (K is the parameter in the relation

$$\langle\phi\rangle_{\text{rms}} = \frac{K}{p\beta\sqrt{2}}\sqrt{t},$$

with t in radiation lengths, where $\langle\phi\rangle_{\text{rms}}$ is the RMS projected angle) for the condition of a cut-off at six standard deviations. The cut-off corresponds to the three standard deviation cut-off imposed on $\overline{\Delta_c{}^2}$ in the experimental analysis. It is relevant to point out that the value for K is some 1·9% lower than that derived from the expression given by Rossi and Greisen (1941).

Figure 1 shows the observed Δ distribution for 20–25 GeV/*c*. Also given is the expected distribution where an allowance has been made for the effect of multiple scattering on the measured momentum and for noise (a small correction at this momentum).

Comparison has been made with expectation both for the RMS and arithmetic mean values for various momentum cells and the results are given in figures 2(*a*) and (*b*).

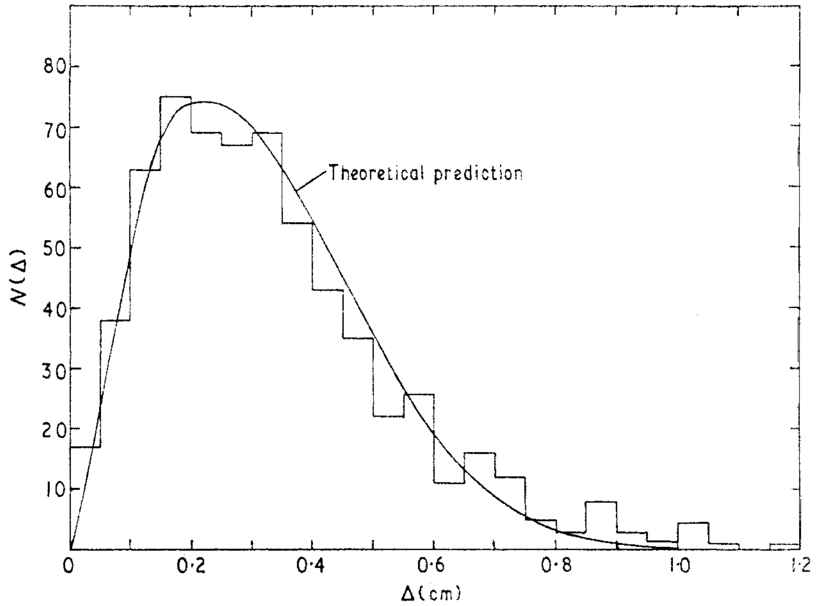

Figure 1. Comparison of observed and expected Δ distributions for incident muons in the momentum range 20–25 GeV/c.

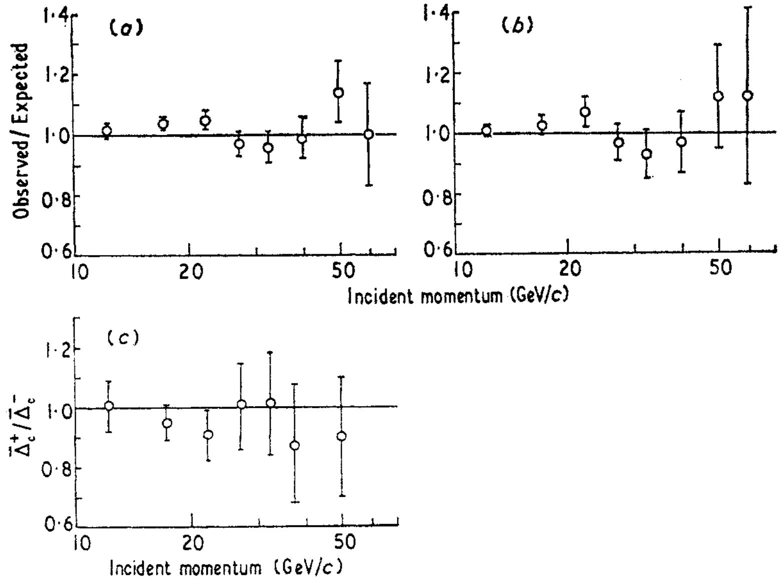

Figure 2. (*a*) Comparison of observed and expected arithmetic means of the Δ distributions. (*b*) Comparison of observed and expected root mean square values of the Δ distributions. (*c*) Comparison of the arithmetic means for positive and negative muons. The errors shown on the graphs are statistical only.

It is seen that there is no significant difference between experiment and theory to the extent of the experimental accuracy: 2% at about 12 GeV/*c* and 17% at about 60 GeV/*c*.

Combining the data over the whole momentum range the ratio of experiment to theory is 1·023 ± 0·012. The error quoted here is purely statistical and to it should be added the small uncertainties in magnet properties and obliquity effects amounting to approximately 1·5%. The final ratio is thus 1·023 ± 0·019.

Taken together with previous measurement of multiple scattering by Lloyd and Wolfendale (1955) below 10 GeV/*c* it can be concluded that there is no evidence for any anomaly in the multiple scattering of muons to 70 GeV/*c*.

The other topic that can be investigated in this experiment is the possibility of a difference in the scattering of positive and negative muons. Although most unlikely an investigation must obviously be made.

The data have been examined in this respect, the measurement error noise being subtracted from positive and negative separately, and the result is shown in figure 2(*c*). The conclusion must be that there is no evidence for charge-dependent scattering although further results of higher precision are clearly desirable.

The authors are grateful to the Science Research Council for financial support by way of Special Research Grants and the provision of Research Studentships. Dr J Torsti is thanked for useful discussions.

References

Ayre C A *et al* 1972 *Nucl. Instrum. Meth.* **102** 19–28
Ayre C A *et al* 1971 *J. Phys.* A: *Gen. Phys.* **4** L75–7
Cooper L N and Rainwater J 1955 *Phys. Rev.* **97** 492–504
Lloyd J L and Wolfendale A W 1955 *Proc. Phys. Soc.* A **68** 1045–65
Rossi B and Greisen K 1941 *Rev. mod. Phys.* **13** 240–309