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USE OF A 200 KILOGAUSS PULSED MAGNETIC
FIELD FOR MOMENTUM MEASUREMENTS OF
HIGH-ENERGY PARTICLES IN NUCLEAR EMULSIONS

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ABSTRACT

The aim of this work is to obtain experience in the accurate measurements of momentum of high-energy particles recorded in nuclear emulsions placed in a high magnetic field. The field characteristics and the method of measurement, as well as the errors due to distortion and multiple scattering, give limitations on the accuracy which can be obtained. The influence of the sources of error on the determination of the momentum and the possible corrections are discussed. In conclusion, some types of improvements which could be made are indicated.

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I. INTRODUCTION

Stacks of G5 nuclear emulsions, 600 μ thick, have been exposed to a momentum-analysed scattered-out proton beam at the CERN PS^{1,2}). These stacks were placed inside a coil energized by a bank of condensers of 300 kilojoule^{3,4}), and giving a pulsed magnetic field H of 180 kilogauss at its peak (Fig. 1) in a volume of the order of 100 cm³. The direction of the magnetic field was perpendicular to the surface of the pellicles. The stacks were roughly cylindrical; their diameter was 6 cm, and the total thickness of the pellicles was about 1.5 cm. The beam entering the emulsions parallel to their plane was 2.5 cm high and 1 cm wide.

We made measurements to determine in the emulsions the radius of curvature, ρ , of the proton tracks. This radius is related to the quantities H (field) and p (momentum) by the equation:

$$\rho \sim \frac{p}{eH}. \quad (1)$$

In our experiment, two known values of p have been used: 13.5 GeV/c and 24.1 GeV/c. The uncertainty in the absolute value was about ± 0.2 GeV/c, and the momentum spread of the beam entering the stacks less than 3%.

II. FIELD CHARACTERISTICS

The maximum intensity of the pulsed field used was 180 kilogauss^{3,4}). The field was measured using a Hall plate calibrated at lower fields (15 to 20 kgauss). The response (Hall voltage) for

an In As Hall plate had been shown to vary linearly with the field from 15 up to 180 kgauss⁵⁾. The maximum uncertainty in the absolute value of the field is $\pm 3\%$. In addition, four main facts limit the accuracy with which the value of the field is known for every track curved in the emulsions.

- i) From pulse to pulse the voltage of the condenser bank energizing the coil can only be reproduced to within $\pm 3\%$.
- ii) The field is not constant at a given time over the volume filled by the emulsions but its distribution over this volume is known, and the maximum change does not exceed 4% ⁴⁾.
- iii) The length in time of the particle burst is not indefinitely small compared with the length in time of the field pulse. Figure 1 shows the shape of the two pulses; 74% of the particles are inside the half-width of the burst. For the remaining 26% the field is between 3 and 10% lower than the maximum value.
- iv) The problem of the synchronization between the field pulse and the particles burst could be an additional source of error. The change in time of the relative position of the two peaks (field pulse and particles burst) must be less than 100 microseconds. For all pulses (about 100) in these exposures, the synchronization was satisfactory and the jitter of the burst was negligible.

Taking into account the sources of error mentioned above, one could expect a standard error in the curvature of 4-5% for 74% of the particles (that is, those entering the magnetic field during the time interval corresponding to the half-width of the burst). The remaining 26% of the particles will pass through the emulsions at lower values of the field both when the field is increasing and when it is decreasing. For this reason, we must expect, and we can calculate, an asymmetric contribution due to these remaining 26% of the particles for which the field is between 3 and 10% lower than the maximum field. For all these particles the momentum will appear to be higher than the value obtained for the 74% mentioned above.

III. MEASUREMENTS

The curvature measurements were made by the usual sagitta method for multiple scattering. The radius of curvature ρ is, in this case, given to a first approximation by:

$$\rho = \frac{t^2}{\bar{D}_2}$$

where $\bar{D}_2$ is the average of the second differences for each track, and t is the cell length. The total length of each track measured was 28 mm. The angle of dip was always less than 1° . At 13.5 GeV/c the measurements have been done with $t = 0.4$ cm. A cut-off has been made rejecting every value D_2 outside $\bar{D}_2 \pm 50\%$. (The justification for this procedure is explained in Section V 1.) At 24.1 GeV/c the measurements have been made with $t = 1.2$ cm; for each track, two sets of independent D_2 have been used for calculating the average value $\bar{D}_2$. It has been checked on a sample at each momentum that both methods of measurements give essentially the same results.

IV. RESULTS

The experimental values of the momentum and of the radius of curvature found for the 150 tracks of 13.5 GeV/c incident protons are shown in Fig. 2. The maximum of the distribution corresponds to 13.8 GeV/c. The distribution is asymmetric, as expected, and the asymmetry found can be calculated from the respective shape of the pulses shown in Fig. 1. The standard error σ evaluated from the experimental points represents 1.3 GeV/c ($\pm 10\%$ of the most probable momentum).

For the tracks of 120 incident protons at 24.1 GeV/c the experimental results are given in Fig. 3. The maximum of the distribution corresponds to 25.7 GeV/c. The standard error σ is about 2.9 GeV/c ($\pm 12\%$ of the most probable momentum).

V. CORRECTIONS

1. Distortion

The influence of distortion can be measured with the help of vertical tracks obtained by an additional exposure perpendicular to the plane of the pellicles. The relevant influence of the distortion is the displacement Δy of the track in the plane of the emulsions, perpendicular to its direction.

For emulsions with small distortion (of the order of 30-40 covan and distributed in a uniform manner over the area measured) the distortion corrections can be neglected.

For less favourable cases, the local displacement Δy can be estimated and taken into account using vertical tracks close to the measured curved track. All the measurements at 13.5 GeV/c have been made in plates showing a small distortion. On the contrary, most of the results at 24 GeV/c have been taken from plates showing a large distortion. In the results we have included tracks where the distortion (Δy) was of the order of one half of the sagitta of the curved tracks.

2. Multiple scattering

Both magnetic curvature and multiple scattering produce a change, $\Delta\theta_M$ and $\Delta\theta_{SC}$ respectively, in the direction of the track after a certain path t in the emulsion. The ratio of these two effects is given by

$$\frac{\Delta\theta_M}{\Delta\theta_{SC}} \simeq 6 \cdot 10^{-5} H \cdot \beta \cdot \sqrt{t} \quad (2)$$

where H is the pulsed magnetic field in gauss, and t is the cell length in cm. For a cell length of 0.4 cm, this ratio is 8, leading to an average of 12% for the error in curvature measurement due to the multiple scattering superimposed on the magnetic curvature. For a cell length of 1.2 cm, the ratio is 14.

Usually in pure multiple scattering measurements a cut-off is used for single values larger than four times the average second difference. If we apply this rule for the component of the multiple scattering which appears in the curvature measurements (about 12% of the curvature) we find this cut-off to be $\bar{D}_2$ (curvature) $\pm 50\%$ for a cell length of 0.4 cm.

VI. CONCLUSIONS

The main conclusion is that when a stack of around 100 cm³ is put in a field of about 200 kgauss, the magnetic curvature of high-momentum particles entering this stack parallel to the surface of the pellicles can be measured with a standard error of 10% on track lengths of about 2 cm.

A small distortion does not affect the curvature measurement. Larger effects of the distortion can be corrected. No measurements have yet been made on tracks with angles of dip larger than 3°. However, the use of thicker pellicles (1200 μ), if they could be well processed without support, would be an improvement.

Three ways of increasing the accuracy of the curvature are clearly indicated.

- i) The length ($\ell \geq 2t$) of track available for measurement should be longer. This means that one should construct larger coils. Theoretically the precision obtained will increase as $\sqrt{\ell}$, if we assume the multiple scattering effect to be the only serious cause of error. [Equation (2).]
- ii) The ratio between the length of the particle burst and the length of the pulsed field must be kept as small as possible, either by reducing the duration of the particle burst (generally followed by a reduction in the intensity of the beam) or by increasing the length of the pulsed field.

iii) The value H of the magnetic field is certainly the most efficient parameter to be increased, but the technical difficulties for producing very high fields (500 kgauss) lead to some strong limitations in coil construction except if single-turn coils are used.

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FIGURE CAPTIONS

Fig. 1 : Variation as a function of time of the field pulse (hall-pulse) and of the particle burst (burst), as displayed on an oscillograph. The height of the pulses is in arbitrary units.

Fig. 2 : Differential distribution (number of tracks per interval of 20 cm) of the measured radii of curvature ρ (in cm) for proton tracks of 13.5 GeV/c momentum.

Fig. 3 : Differential distribution (number of tracks per interval of 50 cm) of the measured radii of curvature ρ (in cm) for proton tracks of 24.1 GeV/c momentum.

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Fig. 1

Fig. 2

number of tracks

Fig. 3