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Abstract

Plural scattering angular distributions of ^{208}Pb on $^{107,109}Ag$ target at very small angles have been measured at $E_{lab} = 873 Mev$.The experimental distribution is well reproduced by Meyer's theory.Using these results the absolute calibration of a position sensitive detector was determined by measuring the limit laboratory angle of the scattering $^{208}Pb + Ag$.

The basic statistical theory of the multiple scattering of charged particles has been developed during the 50's and 60's and a detailed review of this work can be found in Scott[1]. The most important ingredients for the determination of the small angle scattering distributions are the knowledge of the interacting potential and the cross-section. Most of the formulas for the cross- sections used to calculate these distributions have been derived assuming a small value for the Sommerfeld parameter and a Coulomb shielded potential of the Yukawa type firstly suggested by Bohr[2]. Modifications of these formulas for the case of higher values of the Sommerfeld parameter were firstly suggested by Moliere[3]. Meyer[4] was the first to use numerical cross-section computed from classical mechanics and using the Thomas-Fermi potential to take into account the effect of screening. He showed that his method agrees well with Moliere's theory for large number of collisions(multiple scattering) but there are discrepancies in the plural scattering regime. In this paper we present experimental distributions of $^{208}Pb + Ag$, plural scattering at very small angles measured during the E174a experiment performed at GANIL[6] and apply Meyer's theory to analyse it. The measured distributions are very well fitted by this theory and this fact allow us to use it for the confirmation of the absolute calibration of a position sensitive detector used during the experiment by measuring the limit laboratory angle of the scattering of ^{208}Pb on $^{107,109}Ag$.

THE EXPERIMENT

The aim of the E174a experiment was to measure angular distributions of the $^{208}Pb + ^{208}Pb$ scattering at energies below the coulomb barrier with a precision of about $3.10^{-3} degs$ in the absolute angles and 8.10^{-5} in the relative incident energy in order to observe small shifts in the the Mott oscillations caused by effects of long range forces.[5] The experiment was performed at GANIL using a ^{208}Pb beam at E_l=873Mev, and 1129 Mev. The target and detectors were located on a circle of 7m diameter(fig.1). The beam was focalized on a beam scanner also placed on the circle but at zero degrees and opposite to the target. In this way the scattering angle corresponding to a given point on the circle is independent of the point where the scaterring ocourred in the target. Four position sensitive x-y drift- chambers[7] placed at 45-45 degrees and 30-60 degrees operated in kinematical coincidence for the $^{208}Pb + ^{208}Pb$ scattering. The 45 degrees detectors permited to observe the maximum in the Mott cross-section of the $^{208}Pb + ^{208}Pb$ scattering at 90 degrees and thus monitoring the target position during the experiment. The absolute angle of the center of the detectors were determined by means of several measurements of all distances between the components of the experimental arrangement using INVAR filaments calibrated at the SACLAY labotatory. The final precision obtained by this method was of the order of .001 degrees. The relative angular calibration of the 30 degrees position sensitive detector was made at the beginning of the experiment using slotted plates in front of the detectors.

As an independent method we have used a natural Ag target which permits the observation of the limit angles of the scattering $^{208}Pb + ^{107,109}Ag$ in the 30 degrees detector. The beam scanner worked as our detector for the straggling measurements. It consisted of two independent sets of 47 wires disposed vertically and horizontally.

The distance between wires is of 0.5mm and permited us to make measurements from 0 to ±0.095 degrees in steps of .004 degrees. The beam was focalized on the vertical set of wires, i.e. perpendicular to the scattering plane, in a such way that without target only the zero degree vertical wire was hited by the particles.

In fig.2a we show the beam profile obtained with the Ag target. We can see that the distribution is not gaussian with a FWHM of about 0.025 degrees. The fact that the distribution is not gaussian is expected for plural scattering. In fig.2b we also show the spectra of the position sensitive detector at 30 degrees with the Ag target. The two peaks observed correspond to the scattering of ^{208}Pb on ^{107}Ag and ^{109}Ag near by the limit angles. If we dont consider angular straggling the number of counts in the spectra is expected to diverge with a sharp cutoff precisely on the limiting angle. The effect of the angular straggling is to cause the appearance of a "difuseness" in the right side of the peaks shifting its position and decreasing the peak to valley ratio.

The experimental number of counts N_f at a given laboratory angle is calculated by the folding fomula:

$$N_f(\varphi) = \int_{\varphi-\delta}^{\varphi+\delta} N(\varphi')P(\varphi-\varphi')d\varphi' \tag{1}$$

where $N(\varphi)$ is given by: $N(\varphi) = \sigma(\theta)/Jac(\varphi) * Const.$

with σ and Jac respectively the cross-section in the C.M. and the tranformation between the C.M. and the Laboratory sistems and $Const$ takes into account the target thickness, solid angle and beam intensity. The term $P(\varphi)$ is the probability distribution due to the angular straggling. If $P(\varphi-\varphi') = \delta(\varphi-\varphi')$ the Dirac-delta function one sees that $N_f(\varphi) = N(\varphi)$. The value of δ in the integration limits must be choosed sufficiently large to have $P(\delta) \to 0$. Thus,if we determine the straggling distribution from the zero degree beam profile,we are be able to determine the absolute calibration by fitting the 30 degrees spectra with (eq.1).

THE ANALYSIS AND RESULTS

The analysis was performed in the framework of the Meyer's theory[4]. Meyer assumes that the interaction between the colliding particles is of the Thomas-Fermi[8] type and the single scattering cross-section is determined numerically by using classical mechanics. It was shown[4] that the dependence of the cross-section on the energy and the scattering angle can be reduced to a dependence on only one quantity $\eta = \epsilon sin(\theta/2)$ where

$$\epsilon = aE_{cm}/(Z_1Z_2e^2) \tag{2}$$

with

$$a = .885a_0/(Z_p^{2/3}+Z_t^{2/3})^{1/2} \tag{3}$$

$$a_0 = 0.529 \times 10^{-8}cm. \tag{4}$$

The thomas-Fermi radius. The differential cross-section can the be written as:

$$d\sigma/d\eta = \pi a^2 f(\eta)/\eta^2 \tag{5}$$

The function $f(\eta)$ is given by a table[4]. The fraction of the particles scattered in a solid angle $d\omega$ around the reduced scattering angle ϕ is except by a normalization factor determined by the formula[4]:

$$P(\phi)d\omega = d\omega\int_0^\infty exp(-\tau\Delta(z))J_0(\phi,z)zdz \tag{6}$$

where J_0 is the bessel function of order zero and

$$\Delta(z) = \int_0^\infty f(\eta)/\eta^2(1-J_0(z\eta))d\eta. \tag{7}$$

The two important quantities that determine the distribution are the Thomas- Fermi radius and the reduced number of collisions in the target:

$$\tau = \pi a^2 Nt \tag{8}$$

where Nt is the target thickness in number of particles per unit area.

The reduced scattering angle ϕ is related with the laboratory angle φ by the expression below:

$$\varphi = \phi 2Z_1Z_2e^2/(aE_l) \tag{9}$$

The energy dependence of the width of the angular distribution is basically of the 1./E type as we can see in eq.8. In our case the target consisted of a carbon layer of $25\mu g/cm^2$ and $41\mu g/cm^2$ of $^{107,109}Ag$ faced to the beam. Thus in order to calculate the distribution after the target it is necessary to calculate the folding of the two distributions.

$$P_f(\varphi) = \int_{-\infty}^{\infty} P_{Ag}(\varphi')P_{^{12}C}(\varphi-\varphi')d\varphi' \tag{10}$$

where P_{Ag} and $P_{^{12}C}$ are the carbon and Ag distributions respectively.

The final angular distribution is obtained by calculating the distribution as a function of the projected angle φ_x [1] given by:

$$P_p(\varphi_x) = \int_{-\infty}^{\infty} d\varphi_y P_f[(\varphi_x^2+\varphi_y^2)^{1/2}] \tag{11}$$

where the angles φ_x and φ_y are the projection of the scattering angle on the horizontal and vertical planes.(see fig.1a)

In fig.3a(solid line) we present the calculated distribution at zero degrees with eq.11 compared to the data. The only adjustable parameters are a normalization factor and a constant background. We used the values of eq.3 and eq.8 for the radius and reduced number of collisions for the Ag plus carbon foils calculated with the nominal thickness. We have also made measurements with pure ^{12}C targets of $25\mu g/cm^2$ and these data are equally well reproduced. These measurements show that the ^{12}C layer is responsible for about $40 in the ^{12}C+Ag$ target. A small constant background of 35 counts was added to the calculation in order to fit the large angle tail of the experimental angular distribution.

In fig.3b we show the fit of the 30 degrees spectra with eq.1. It was obtained by minimazing the χ^2 varying the absolute calibration and a constant normalization factor. The relative calibration was obtained from the spectra with the slotted plate placed in front of the detector in the beginning of the experiment. The angular straggling distribution was calculated in the same way as in the zero degree distribution. Only two effects must be taken into account in order to explain the increase of the width of the straggling distribution at 30 degrees:the true 208Pb energy after the scattering in the Ag nuclei and the thickness effectively traveled by the projectile at 30 degrees since the target was keeped perpendicular to the beam during the experiment.

The absolute calibration obtained for the best reduced chi-square($\chi^2 = 1.0$) agrees with those obtained by the geometrical method provided we use a negative Q-value of 0.95Mev in the kinematics. It is equivalent to a displacement of $1.4X10^{-2}$ degrees in the absolute calibration of the 30 degrees detector. This displacement was also observed in the comparision between the scattering angles of the two lead nuclei in coincidence at 45 and 30-60 degrees and the relativistic kinematics calculation[6]. One possible explanation for this negative Q-value is the energy loss due to the atomic excitation of the electrons and the formation of molecular states[9] during the collision.

The final precision in the determination of the absolute calibration obtained by this method was estimated by fixing the relative calibration and allowing the absolute calibration to vary around the minima in the total chi-square curve up to $\chi^2_{min} + 1$. This criteria furnished a precision of .004 degrees.

CONCLUSIONS

We have measured angular distributions of the $^{208}Pb +^{107,109} Ag,^{12} C$ scattering at angles from zero to 0.19 degrees with steps of .004 degrees in the laboratory. The distributions are not gaussian and are well adjusted by Meyer's theory[4] providing a new test for this theory in the case of high values of the Sommerfeld parameter.

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figure captions

- Fig.1 Experimental setup used in the E174a experiment
- Fig.2a Spectra of the beam scanner at zero degrees with the Ag target
  Fig.2b Spectra of the position sensitive detector at 30 degrees with Ag target
- Fig3a Spectra of the beam scanner at zero degrees compared with the calculated distribution from eq.11(solid line).
  Fig.3b The spectra of the 30 degrees detector (n^o of counts X angle) compared with the calculation using eq.1(solid line).

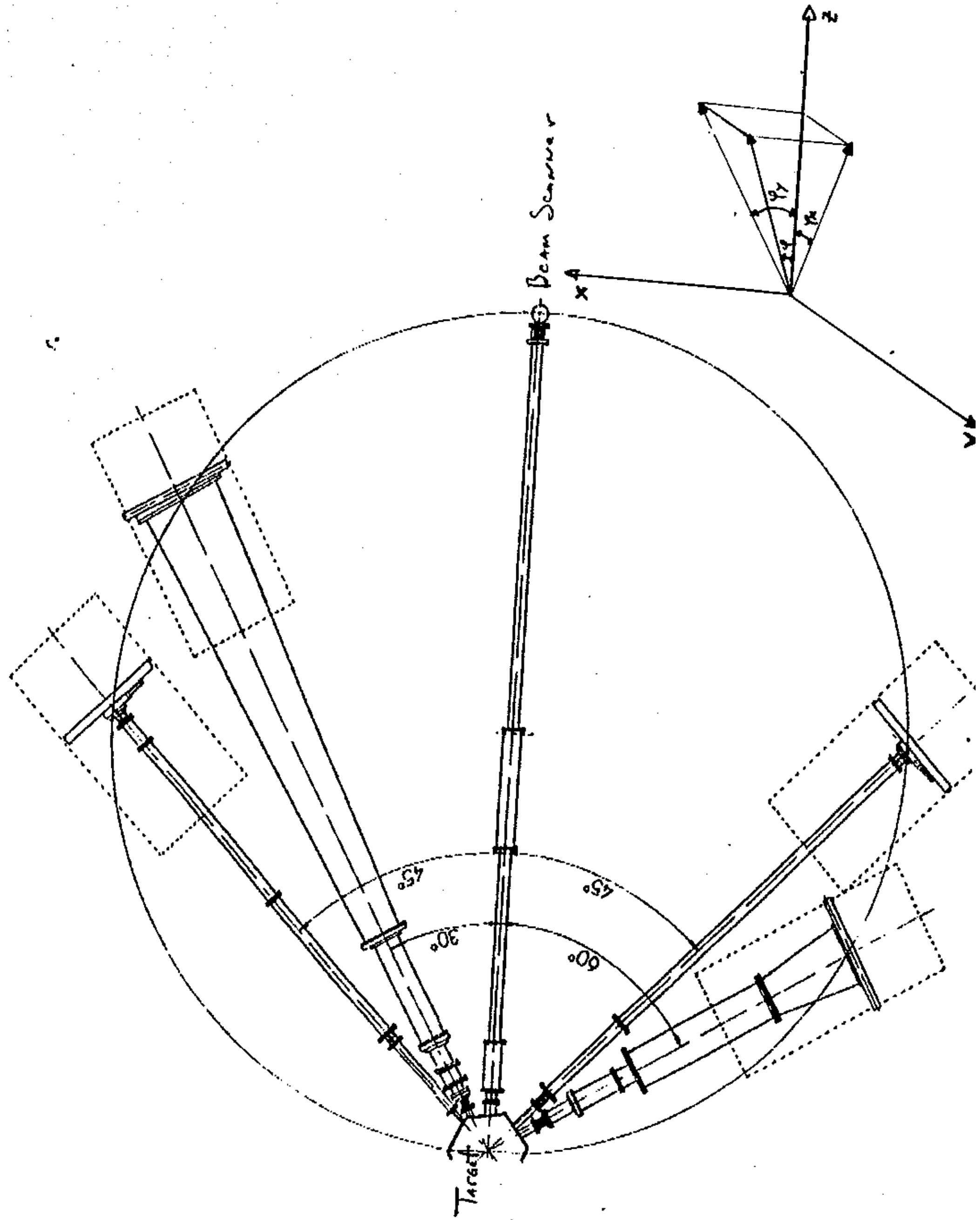

Fig 1

Fig 2a

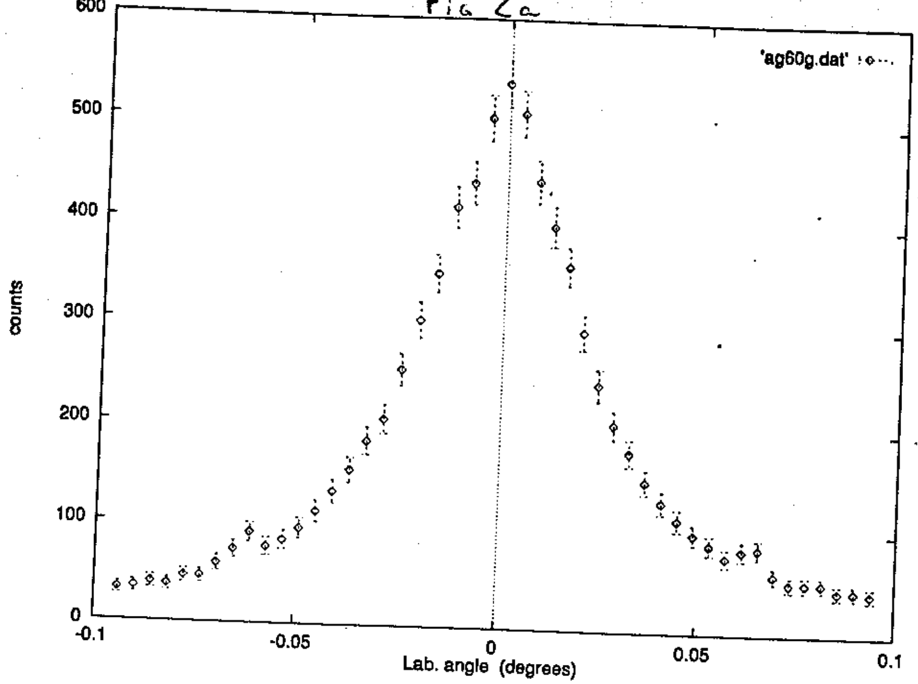

Fig 2b

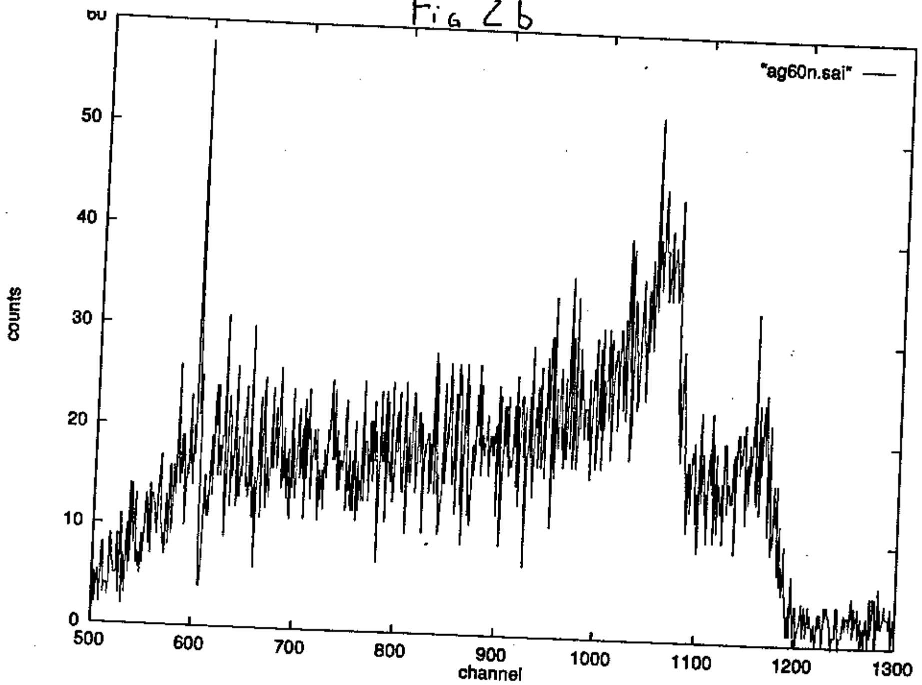

Fig 3a

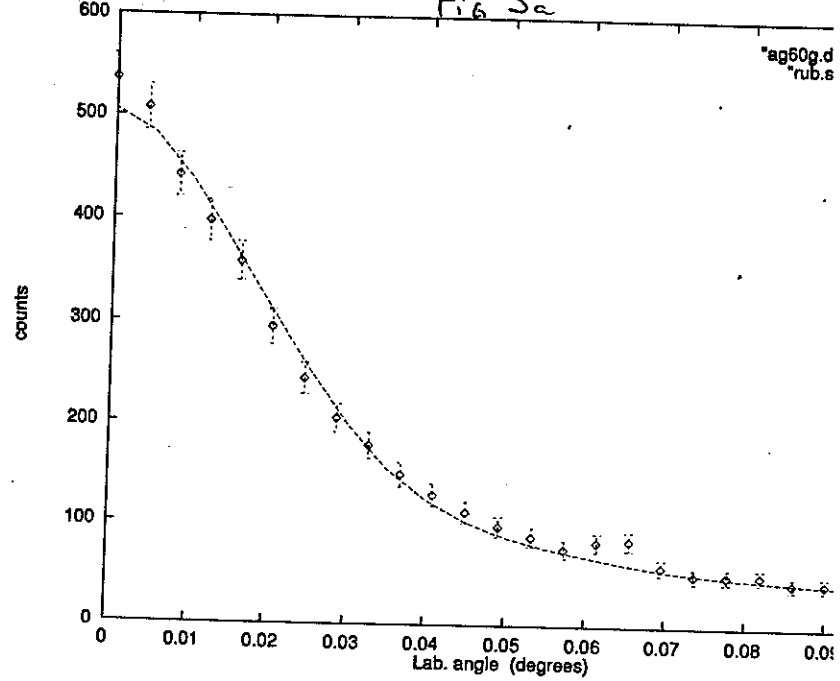

Fig 3b