AN ABSOLUTE MEASUREMENT OF THE p+p ANALYZING POWER AT 183 MEV

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The analyzing power A_y for p+p elastic scattering at θ_{lab}=8.6° and a bombarding energy of 183.0 MeV has been measured. The measurement provides a normalization for recent Cooler data (CE08, p+p scattering in the Coulomb-nuclear interference region[1,2]) and serves as a calibration standard for polarized beams in this energy range. The absolute scale for the measurement has been obtained by comparison with p+C elastic scattering at the same energy at an angle where A_y is very nearly unity.

The advantage of observing p+p scattering concurrently with p+C scattering is that the two reactions sample the same beam with the same target. Recently it has been shown that A_y for p+C scattering is unity at T=189±2 MeV and θ_{lab}=17.3° ± 0.3°.[3] Close to the maximum ($12° \leq \theta_{lab} \leq 22°$) the dependence of A_y upon T and θ_{lab} can be obtained by fitting a simple parabola to p+C scattering data[3,4] in the energy range between 160 and 200 MeV. From the fit one concludes that at T=183.0 MeV the maximum analyzing power is $A_{y,max}$=0.998±0.002 at θ_{lab}=17.75° ± 0.16°.

The experiment was carried out in the 64-inch scattering chamber using a CH_2 target of 1.1 mg/cm^2 thickness. The detector arrangement is shown in Fig. 1 and consisted of two left-right symmetric telescopes of plastic scintillators (3.2 mm thick) and NaI scintillators (127 mm thick) to stop 220 MeV protons. The ΔE detectors defined the solid angle (4.02×10^{-4} sr). In order to cleanly define p+p scattering events a coincidence between the forward going proton and the recoil proton was required. The recoil protons were detected with two silicon surface-barrier detectors, which subtended about 1.5 times the recoil angle associated with the forward protons.

Energy and time information for all detectors was recorded event by event. In addition, the scaled beam current integrator and discriminator counts for all detectors were written to tape every 10 seconds. When replaying the data, it was thus possible to determine the time-dependence of the recorded rates. It was discovered that the gain of a given NaI detector was related to the rate at which the respective discriminator fired. Over the range of rates observed in a given run, the gain was found to be linearly dependent on rate. This information was used to apply a rate-dependent correction to the recorded energy signals before any further processing. Examples of measured spectra, after correction, are shown in Fig. 2. The FWHM width of the p+C ground-state peak is 1.5 MeV, corresponding to a resolution of 0.8 %.

Data were accumulated with the direction of the polarization vector either up or down with respect to the scattering plane. The spin orientation was reversed every 10 seconds. Runs with two different CH_2 targets, with a carbon target, with different target

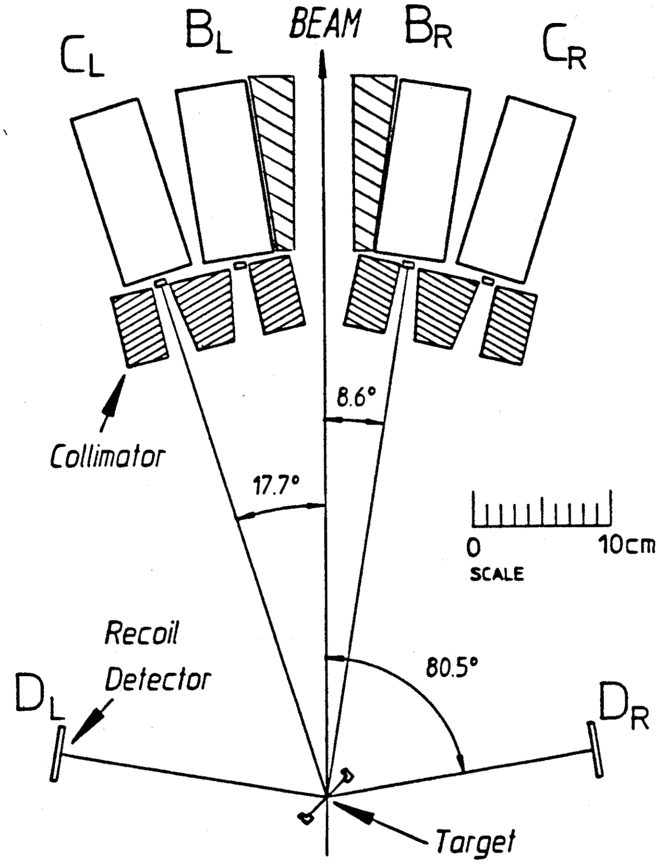

Figure 1. Top view of the experimental arrangement. Shown are the scintillator telescopes $B_{L,R}$ and $C_{L,R}$ for measuring p+p and p+C elastic scattering as well as the silicon surface-barrier detectors $D_{L,R}$ to detect p+p recoil protons. The shaded parts are brass collimators with conical holes and shielding between the beam and the inner detector telescopes.

orientations, with different average beam intensities, and with the beam position displaced from the center position were carried out to provide the data base needed to assess the systematic uncertainties of the measurement. The result from a given run consists of nine numbers, from which the analyzing power for p+p scattering can be determined either from the left or the right telescope alone. Note that the two polarization states are not assumed to be equal. The final result is then the average $A_y(^1H)$ between $A_{y,L}(^1H)$ and $A_{y,R}(^1H)$, which is insensitive to left-right positioning errors, depending only on the angle between the two inner telescopes, which has been determined with special care (see below).

The spectrum from the inner telescopes at 8.6°, for which a coincidence with the microstrip detector was required, contained unwanted events arising from p+C scattering accompanied by an accidental pulse in the associated microstrip detector. Most of these events were removed by applying a gate to the microstrip spectrum. Remaining background events (for which the accidental pulse fell within this gate) were removed by acquiring data with a pure carbon target under otherwise identical conditions (including the gate in the microstrip spectrum), and subtracting the result, properly scaled with target thickness and accumulated beam current, from the 8.6° spectrum obtained with a CH_2 target. The spectrum resulting from this subtraction is shown in Fig. 2a. The remaining smooth component outside the p+p peak is due to p+p events misplaced in energy by reaction losses and outscattering.

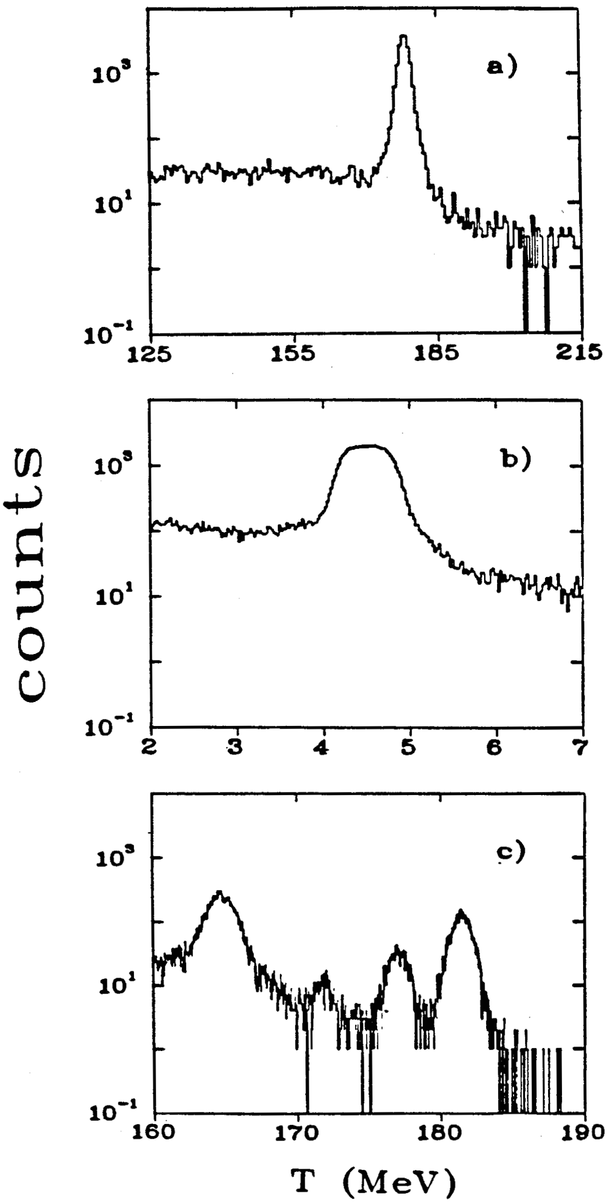

Figure 2. Representative energy spectra. The spectrum of forward protons from p+p scattering in the NaI scintillators at 8.6° ($B_{L,R}$ in Fig. 1) is shown in a). For these protons a coincidence was required with the recoil protons detected with a microstrip detector ($D_{L,R}$ in Fig. 1); the microstrip spectrum is shown in b). A spectrum obtained with a pure carbon target, scaled to the same integrated luminosity, has been subtracted to arrive at the spectrum shown in a). The singles spectrum obtained with the NaI scintillators in the outer telescopes ($C_{L,R}$ in Fig. 1) is shown in c). A rate-dependent gain correction has been applied to spectra a) and c). Note that the groundstate peak is cleanly separated from the first excited state at 4.4 MeV.

Prior to the experiment an optical reference line was established through the centers of two quadrupole lenses 3 m upstream of the scattering chamber. A beam alignment scintillator at the target location was centered on this line. During the run, the beam was positioned on target by the use of this scintillator. Individual telescope angles were determined by triangulation with a precision of $\pm 0.2°$. The geometry was fixed during the experiment and the position of all detectors was checked again afterwards. The angle between the inner telescopes could be measured more accurately since it is given by the distance between the E detectors (known to 0.5 mm), yielding a left-right average for the p+p scattering angle of θ=8.64°±0.07°. From the known angle dependence $dA_y(^1H)/d\theta_{lab}$=0.011 deg^{-1} at the angle and energy of interest, one finds that this angular uncertainty contributes δA_θ=0.0008 to the final error.

We extracted a value of A_y=0.2122±0.0017 for p+p scattering at θ_{lab}=8.64° ± 0.07°. The quoted error has been obtained by quadratically combining the uncertainties due to statistics (δA_S=0.0013), the uncertainty in the angle of the inner detectors (δA_θ=0.0008), the uncertainty in the current integration (δA_I=0.0004), and the error in the p+C analyzing power ($\delta A_C=0.21\cdot\delta A_y$(C)=0.0004). Also included was an error δA_T=0.0004 from the uncertainty of the bombarding energy, deduced from the known $dA_y(^1H)/dT$ = 0.0011 MeV^{-1}. The data set has a χ^2 per degree of freedom of 0.96.

When comparing the present result to previously available experimental information, we note that there is a shortage of analyzing power data for p+p scattering at medium energies, especially at small angles. Between 150 and 300 MeV only four experiments have reported analyzing power data forward of θ_{cms}=30° (refs. 5-8). Three of these are more than 25 years old. The two measurements that are closest in angle to the present result, and bracket it in energy are $A_y(^1H)$=0.241±0.036 at 174 MeV and θ_{cms}=20.8° (Ref. 5), and $A_y(^1H)$=0.264±0.025 at 209 MeV and θ_{cms}=18.9° (Ref. 8). Clearly, the present result constitutes a significant addition to the data base for p+p elastic scattering.

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