# MEASUREMENT OF THE ELASTIC AND INELASTIC CROSS SECTIONS FOR PROTON SCATTERING ON $^{36}$Ar AND $^{42,44}$Ar IN INVERSE KINEMATICS

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In the last two years systematic measurements of the energies of the first excited states $E(2_1^+)$ and the corresponding B(E2) values of neutron rich even-even isotopes in the mass A=40 region have been performed at the NSCL using Coulomb excitation [1-3]. These measurements revealed a rapid weakening of the $N = 28$ shell closure below $^{48}$Ca and a region of moderate deformation around $^{40,42}$S. The question arises how the nuclear structure of these nuclei is influenced by the neutron and proton distributions. In Coulomb excitation one probes the charge distribution in the nucleus and no information is gained about the neutrons. Proton scattering in the energy range of 10-50 MeV is very sensitive to the neutrons (as compared to the protons) and the combination (p,p') results with earlier Coulomb excitation results allows the determination of the proton and neutron transition matrix elements $M_n$ and $M_p$ [4]. From the homogeneous collective model we expect that $M_n/M_p = N/Z$, meaning that protons and neutrons participate equally in the excitation of the nucleus, but we also expect, especially for single closed shell nuclei, some shell structure effects. (E.g. in a nucleus with a closed neutron shell we expect only protons to participate in the excitation.) These effects are particular interesting as one goes to larger and larger neutron excess. In ref. [5] Kelly *et al.* showed that there is a considerable isovector contribution to the excitation of the first excited state for $^{38}$S which is neither magic in protons nor in neutrons. Therefore one might find surprising effects as one approaches the neutron drip line. In this experiment we measured the elastic and inelastic proton scattering cross sections on $^{36,42,44}$Ar in inverse kinematics.

Radioactive beams of $^{42,44}$Ar were produced in the A1200 fragment separator from a 70 AMeV $^{48}$Ca beam provided by the K1200 cyclotron. An energy degraded primary beam (E/A = 33 MeV) of $^{36}$Ar was also used as a check of method. These beams were transported to the S2 experimental station where the secondary target was located. The beam energy of the secondary beams was E/A = 33 MeV and the purity was close to 99%. After impinging on a $2.7\mathrm{mg/cm^2}$ $\mathrm{CH_2}$ target the scattered beam particles were detected in a fast-slow phoswich detector, allowing identification of the ejectile. (See figure 1 for a schematic drawing of the setup.) The recoiling protons were detected in a set of 4 Si-telescopes each of which consisted of one Si-strip detector ($300\mu\mathrm{m}$) for position and energy measurement followed by two Si PIN detectors (each $500\mu\mathrm{m}$). The (single sided) Si-strip detector gave position information in two dimensions: Position in one direction is simply given by the strip number. Each strip was resistive and read out on both sides. From charge division it follows that $Y_1/(Y_1 + Y_2)$ (where $Y_1$ and $Y_2$ are the signals measured on both ends) is proportional to the position on the strip. The measured resolution for a 5 MeV total signal was about $500\mu\mathrm{m}$ compared to the strip width of 3 mm. The Si detectors were located about 23 cm from the target arranged to cover angles in the CM from about $\theta_{cm} = 20°$ to $\theta_{cm} = 45°$. Particle identification in the Si-detectors was done by the TOF method for particles stopping in the strip detector or by a $\Delta$E--E measurement otherwise. Protons up to an energy of 14.5 MeV were stopped in the Si detectors and the incident energy of higher energy protons was deduced from the energy loss.

In order to determine the scattering angle we need to accurately track the incoming projectile. Unfortunately the position resolution of the PPACs was not as high as expected; however, a novel technique was employed to obtain the trajectory, which gave satisfactory results. The new method is based on the

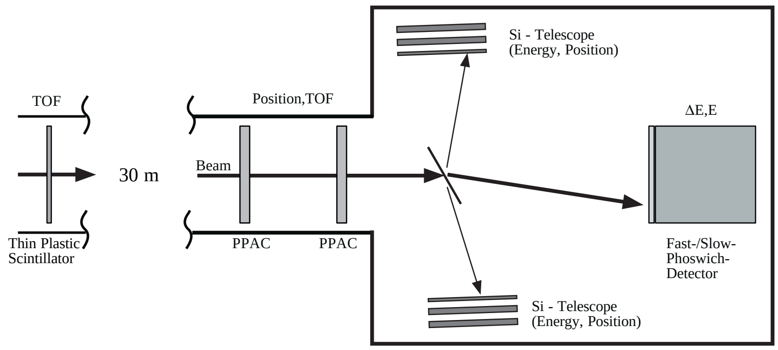


Figure 1: Setup around the secondary target.

following: The (straight line) trajectory of the particle (in one dimension) is completely defined by the slope and the position at some point along the particle path. The phase space ellipse (PSE) of the beam relates the slope of the trajectory to the particle position. Therefore knowledge of the orientation of the PSE together with *only one* position measurement gives the trajectory, since we can use the orientation of the PSE to obtain the slope. The beam emittance introduces an error since the PSE has a certain volume, but the errors in the calculated target position and in the calculated slope of the trajectory (both of which are needed to calculate the scattering angle) are smaller than the errors obtained by using 'traditional' tracking, where one calculates the trajectory from two position measurements. In practice one uses two tracking detectors to obtain the orientation of the PSE and then applies the previously described method to both detectors, or one treats the slope of the PSE (i.e. $\frac{d\frac{dx}{ds}}{dx}$) as a free parameter and adjusts it to obtain the best resolution. Taking a properly weighted average between the results obtained from each detector gives the position on the target and the incident direction with sufficient precision. See figure 2 for a comparison of the resolution using the old and the new method. The resolution in excitation energy is almost a factor of two better.

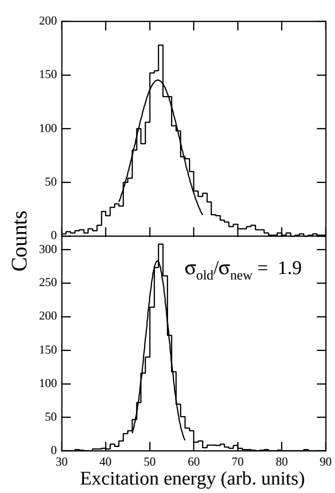


Figure 2: Measured excitation energy with angular cut in $\theta_{cm} = 25° - 30°$. The top panel shows the spectrum obtained if normal tracking is used, whereas the bottom panel shows the same spectrum but the new tracking method is applied. The resolution improves by almost a factor of 2.

Figure 3 shows experimental results for $^{36}$Ar. The top left hand panel shows the proton energy versus the scattering angle (both) in the laboratory system. We can see the kinematic lines belonging to the ground state and the first excited state (also marked by line). The top right hand panel shows a scatterplot of the excitation energy versus the center of mass scattering angle. The data points are grouped around two horizontal lines: One line is centered around $E^{*} = 0$ (elastic scattering) and the other around $E^{*} = 1.97$ MeV (inelastic scattering from the first excited state). The histogram in the bottom shows an excitation energy spectrum for the angular range of $\theta_{cm} = 30° - 34°$. The spectrum is fitted with two gaussian peaks and the well known excitation energy of the first excited state in $^{36}$Ar of 1.97 MeV is well reproduced (this measurement: 1.98(6) MeV). The inset shows preliminary cross sections for elastic and inelastic scattering together with ECIS calculations. The optical model parameters for the ECIS calculation were obtained from ref. [6]. The new data follow the previous measurement (ECIS calculation) quite well; however, The data points in the range of $\theta_{cm} = 30° - 40°$ for the elastic cross section are too low compared to the previous measurement. This might be due to an inaccuracy in the determination of the proton detection efficiency. In the near future we will obtain a better understanding of the Si-array through a Monte Carlo Simulation, which will include the beam profile, beam energy spread, energy loss in the target, and all detector responses.

The next step will be to extract the (p,p')-$\beta_2$ deformation parameters and to compare this to the Coulomb excitation results. This will lead to a determination of the isovector contributions to the excitations of the first excited states in these nuclei.

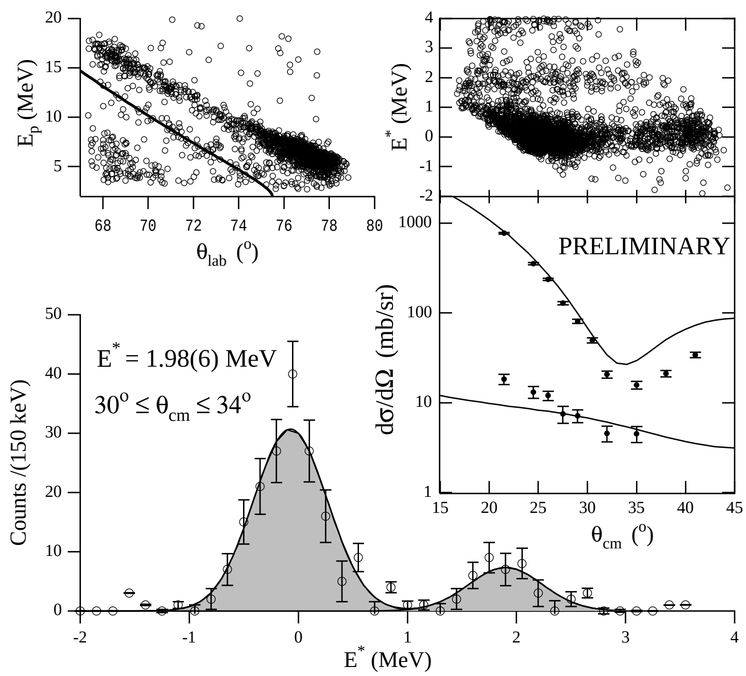


Figure 3: Experimental results for $^{36}$Ar: Shown here are the measured kinematic lines in the laboratory (top left) and the center of mass (top right) system. The bottom axis shows the excitation energy spectrum for the angular range $\theta_{cm} = 30° - 34°$. The inset shows preliminary cross sections (see text).

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