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The Polarization Spectrograph DUMAS

T. Noro[+], T. Takayama[+,*1], H. Ikegami[+], M. Nakamura, H. Sakaguchi, H. Sakamoto[*2], H. Ogawa[*3], M. Yosoi, T. Ichihara[*4], N. Isshiki[*5], M. Ieiri, Y. Takeuchi, H. Togawa, T. Tsutsumi and S. Kobayashi

+ Research Center for Nuclear Physics, Osaka University
Ibaraki, Osaka 567, Japan
Department of Physics, Kyoto University, Kyoto 606, Japan

A new type spectrograph for double scattering experiments was successfully constructed at RCNP. This spectrograph was designed to measure the momentum and the polarization of particles separately and simultaneously. This basic idea has made it possible to construct an efficient polarimeter system with an efficiency of 1×10^{-4} and an effective analyzing power of 0.86 for 65 MeV protons and it became feasible to obtain high quality spin-transfer data within a reasonable measuring time. Outlines and properties of the spectrograph and the counter system are presented with a few examples of data taken by this facility in this paper.

§1. Introduction

Recent progress in polarized ion sources has made it quite easy to measure analyzing powers of nuclear scattering or reactions. At the present time, measurements of polarization transfer coefficients which require information about polarizations of both the incident and the outgoing particles have also become feasible. Actually, following the pioneering work using a Si-polarimeter[1] or a focal plane polarimeter[2], intensive work has been done in a few laboratories, and precise data are being accumulated and a part of this work has been reported at this conference.

In order to measure the polarization of emitted particles, we have to rely on double scattering and it is important for an efficient measurement that a detecting facility satisfies the following conditions:

a) Good energy resolution for the first scattering.
b) High efficiency. Namely, counting with large solid angle for both the first and the second scatterings and the use of a thick second target.
c) Broad energy range.
d) High effective analyzing power of the polarimeter. In order to realize this, the energy resolution for the second scattering should be good enough to separate elastic events from other events in the energy region at RCNP.
e) To allow a high rate of good events. Signals corresponding to the particles which were not scattered by the second target should be reduced.

A new type spectrograph named DUMAS (Dual Magnetic Spectrograph) was constructed at RCNP in order to measure the polarization transfer. The most distinctive feature of this spectrograph is the existence of two foci, one of which is suited for measurements of the energy of particles and another is suited for measurements of the polarization. This feature permitted us to design a polarimeter system which is independent of an energy measurement system, and an efficient counter system which satisfies the above conditions reasonably well was developed and constructed successfully.

This spectrograph and the counter system are now being used in several kinds of experiments and high quality data comparable with single scattering data have been produced.

§2. Magnet system of DUMAS[3]

This spectrograph consists of five main magnets (Q1-D1-Q2-D2-Q3) and two small correction magnets (M1 and M3) as shown in Fig. 1. All these magnets are mounted on a carriage which can rotate from -60° to 140° round the center of the scattering chamber.

Ion optical geometry of the spectrograph and the results of the ray-tracing calculations are shown in Fig. 2. Particles scattered or emitted from the first target (TP) are momentum-analyzed in the first half of this system and are focused dispersively on the first focal plane (FP1). The momentum dispersion which is produced by the first half is canceled out by the D2 magnet and the particles are focused again onto the second focal point (FP2) achromatically. Therefore, one can get information about the momenta of the particles from a transmission-type position sensitive detector placed at FP1 and, at the same time, get information about their polarization using a polarimeter system placed at FP2, which consists of a second scatterer and detectors for scattered particles.

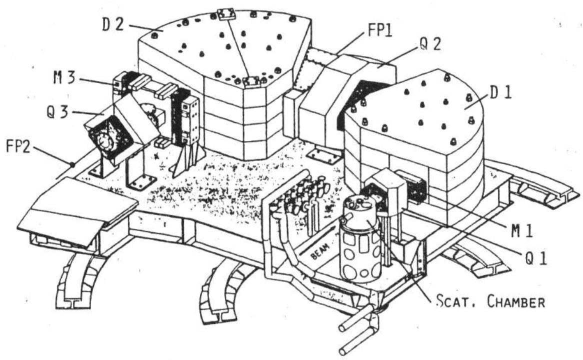


Fig. 1. Bird-eye view of polarization spectrograph DUMAS.

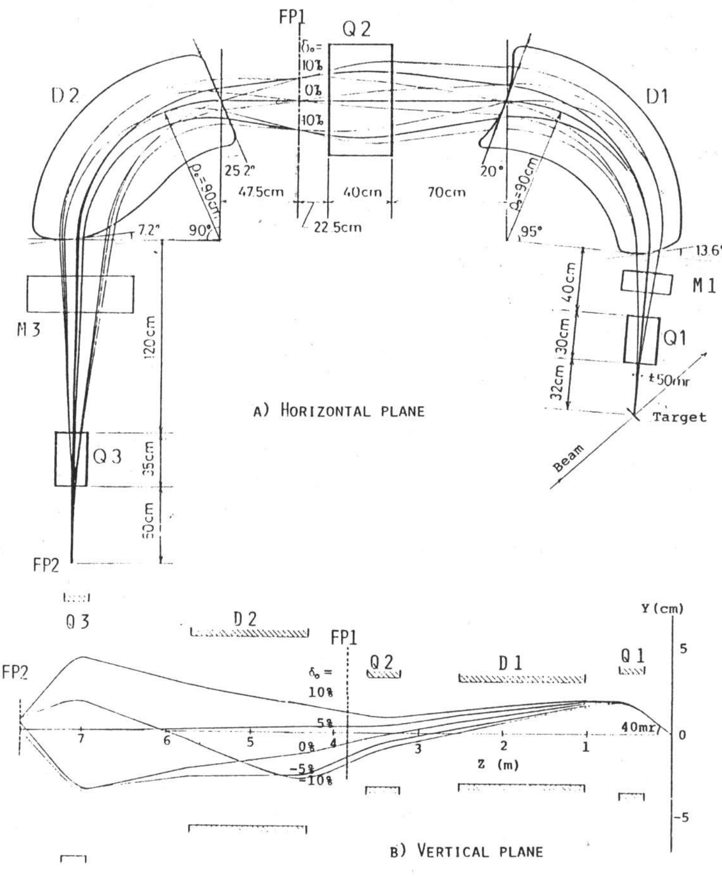


Fig. 2. Optical geometry and calculated trajectories of DUMAS

In this system, there are two additional advantages which are unusual in an ordinary spectrograph. The first is that the overall deflection angle from TP to FP2 is almost constant independently of orbit radius or injection angle to the system in the first order. This fact is important especially in measurements of horizontal components of polarization such as a $K_x^{x'}$ measurement, because deviations of deflection angles cause different spin-precession angles in the magnetic field. The second advantage is that the path lengths from TP to FP2 are same in the first order for particles with the same momentum. This may be useful to reduce chance coincident events in the case of correlation measurements or to identify particles by a TOF technique when DUMAS is used as a momentum filter.

Momentum resolution of this system depends on the orbit radius of particles in the dipole magnets and the properties of a primary beam itself. The overall resolution measured on FP1 is plotted in Fig. 3 as a function of the orbit radius. The open circles show the resolution when a primary beam is transported onto the target monochromatically, and hexagons show those for achromatic beam transportation. The difference between these two kinds of data comes from the different energy spread of the primary beams and the different spot size of the beams on the target. In a usual double scattering measurement, we use the achromatic beam transportation in order to transport a beam from the cyclotron onto the target without serious intensity loss. In the case of monochromatic beam transportation, less than 10% of an extracted beam reaches the target. All the data in Fig. 3 were obtained using a single wire proportional counter as a position counter at the first focal plane, the position resolution of which is about 0.3 mm.

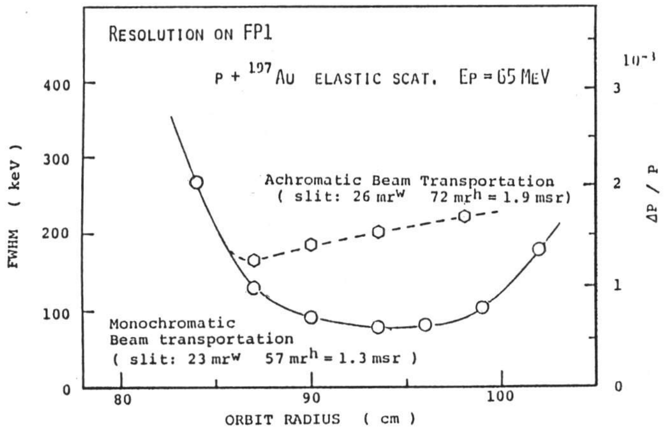


Fig. 3
Overall resolution of the system measured at FP1. The left ordinate shows the absolute energy resolution and the right one shows the momentum resolution Δp/p.

It should be mentioned here that we use a multi-wire proportional counter (MWPC) as the position counter in the case of a double scattering measurement because a count rate at this position is quite high. In this case, the position resolution at FP1 is determined by the wire spacing (2 mm) of the counter. Roughly speaking 2 mm resolution corresponds to the energy resolution of 200 keV at 65 MeV. Thus the actual resolution in a typical double scattering experiment was 200~400 keV.

The confirmed ion optical properties of this magnet system are listed in Table 1.

§3. Counter system for polarization transfer measurements[4]

The counter system consists of a position counter for momentum tagging placed at FP1, a polarimeter system named MUSASHI at FP2 and electronic circuits to read out signals from those counters.

As mentioned in the previous section, a MWPC is used as a tagging counter. The specifications of this counter are listed in Table 2. A typical counting rate of this counter was 100-300 kcps exclusive of background caused by γ- and x-rays. The efficiency of this counter was better than 99% at the counting rate of 5 kcps per wire and the counting loss was allowable when measured particles were distributed in the wide range of the counter. However, when the particles were concentrated on a few wires, a serious reduction of the efficiency occured. In such cases, a movable slit (tagging slit) positioned in front of the tagging counter was used in order to stop undesirable particles.

The polarization of emitted protons is measured by means of the p-^{12}C elastic scattering using the polarimeter MUSASHI, which is shown in Fig. 4. Seven carbon sheets are arranged in the target vacuum chamber as shown in Fig. 4(c). The thickness of the sheet is chosen according to the proton energy.

Table 1

Achieved or confirmed properties of DUMAS

Maximum energy	$E_{max} = 110\ Z^2/A$ MeV
Orbit radius	ρ = 84-98 cm
Spectrum range	±7.7% in momentum (±15% in energy)
Maximum solid angle	$\Delta\Omega_{max}$ >5.6 msr (75 mr horizontal × 75 mr vertical)
Deflection angle	185°
Length of central orbit (ρ=90cm)	ℓ = 7.80 m
Maximum deviation of the path length for particles with central momentum	$\Delta\ell/\ell$ = 0.12%
1st focal plane	
Size	40 cm horizontal × 8 cm vertical
Energy dispersion	$\Delta x \cdot E/\Delta E$ = 700 mm (ρ = 98 cm) 1015 cm (ρ = 84 cm)
Tilted angle	0° (normal to the central orbit)
Energy resolution	$\Delta E/E = 1/850^*$ (monochromatic beam transport) 1/350 (achromatic beam transport)
2nd focal point	
Energy dispersion	0 (less than 10 mm).
spot size (FWHM)	7 mm horizontal × 5 mm vertical

* solid angle : 24 mr horizontal × 54 mr vertical
= 1.3 msr

Table 2

Specifications of MWPC

	large	middle	small	tagging
* anode	20 μm gold-plated tungsten wire			
* cathode	125 μm Cu/Be			
* wire spacing	2 mm	2 mm	1 mm	2 mm
* anode cathede gap	6 mm	6 mm	3 mm	8 mm
* effective region	350×350 mm^2	350×200 mm^2	70×70 mm^2	400×80 mm^2
* gas mixture	argon : isobutane : freon : methylal = 66 : 33 : 0.3 : 4 (magic gas mixture)			
* supplied voltage	4.7 kV	4.7 kV	3.7 kV	5.6 kV

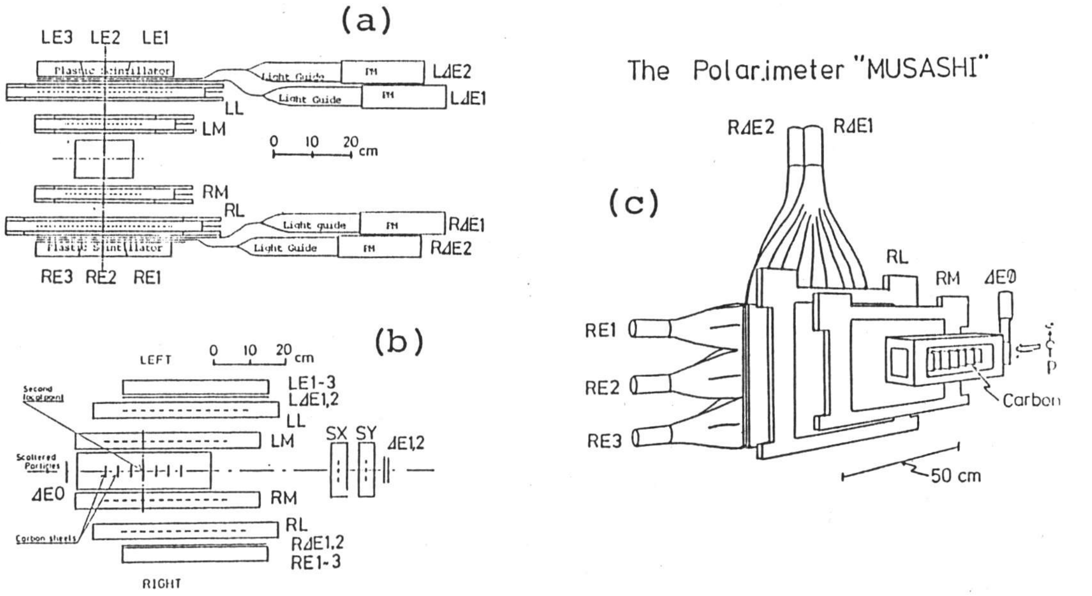


Fig. 4. The scale drawing of the polarimeter MUSASHI. (a) front view, (b) top view and (c) schematic representation (The left half and the profile monitor are omitted to avoid confusion.)

Particles scattered by one of these second targets are detected by a left or a right counter array; each consists of two (large and middle) MWPCs and a set of plastic ΔE-E scintillation counters. Both the MWPCs inform us of the horizontal position of the particle's trajectory. So we can trace back the trajectory onto the beam axis and we can know from which target and at which angle the particle was scattered. The E counter is divided into three pieces in order to correct the effect caused by off-plane scattering and to improve the energy resolution.

A counter array on the beam axis which consists of two small (XS and YS) MWPCs and two plastic scintillators (ΔE1,2) is used to monitor the profile of the incoming beam during the measurement and also used to measure the analyzing power of the first scattering or reactions.

A trigger signal for the read out system is made by the logic of ΔE0·XΔE1·XΔE2·(XE1+XE2+XE3) for left (X=L) or right (X=R) events. Signals from the profile monitor are thined out and only from 10^{-4} to 10^{-3} of those are read. All the signals from the tagging and the MUSASHI counters are transmitted to the counting room about 100 m away from the experimental area using a CAMAC branch highway and are processed by a PDP 11/44 computer. A typical counting rate of the whole system was about 200 cps with 10% dead time.

The effective analyzing power of this polarimeter is shown in Fig. 5. Seven carbon sheets are used as the second targets and each sheet is 157 mg/cm^2 thick. The efficiency of the system is about 1×10^{-4} for 65 MeV protons.

Overall consistency of data measured by this system was checked using proton elastic scattering from spin-zero targets because the depolarization of protons should be unity. The result was consistent with the prediction within the accuracy of 0.01.

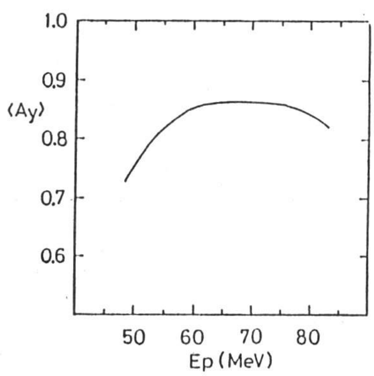


Fig. 5. The effective analyzing power of the polarimeter MUSASHI plotted as a function of the incident proton energy.

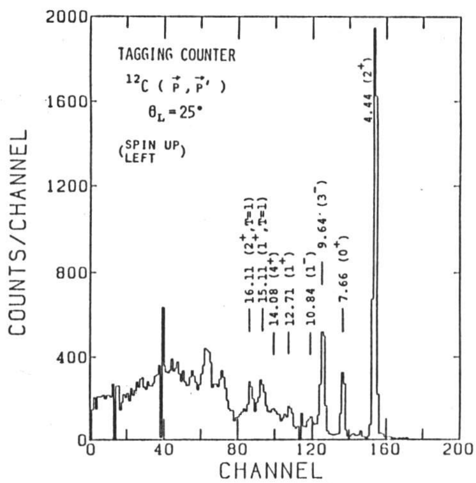
§4. Examples of measured spectra and data

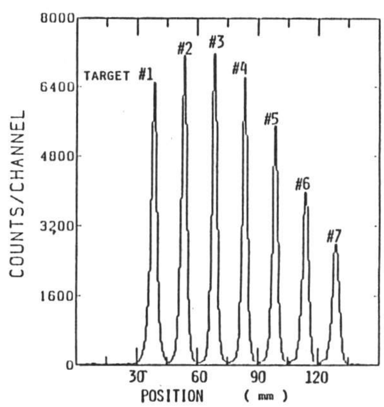
Since the measurements of the spin rotation parameters have been reported in another paper presented by Sakaguchi at this conference, we will show the data for proton inelastic scattering from ^{12}C target at the energy of 80 MeV in this paper.

A momentum spectrum of scattered protons measured by the tagging counter is shown in Fig. 6. The elastic scattering events were eliminated using the tagging slit in front of the counter. The resolution was about 2 channels, 370 keV FWHM. Figure 7 is a traced-back spectrum of secondary scattered protons onto the beam axis of the polarimeter MUSASHI. Each peak corresponds to the scattering from a target sheet and the separation of these peaks is very good.

Q-values for the second scattering can be derived from energy values measured by the tagging counter and the E-counter of MUSASHI with a correction for kinematical energy shift, energy loss in the second targets and the ΔE-counters, and position dependence of the E-counters. The result is shown in Fig. 8. The separation of the elastic peak from other peaks was reasonably good.

The results of the data reduction are shown in Fig. 9 for the inelastic scattering exciting the 15.11 MeV state[5]. The cross sections ($d\sigma/d\Omega$) and the analyzing powers (A_y) were measured by the high resolution spectrograph RAIDEN. Spin-flip probability data (S) and polarization data (P), which were measured by DUMAS system within a four-days of machine time, are preliminary ones. The errors shown in the figure include statistical and background subtraction errors.





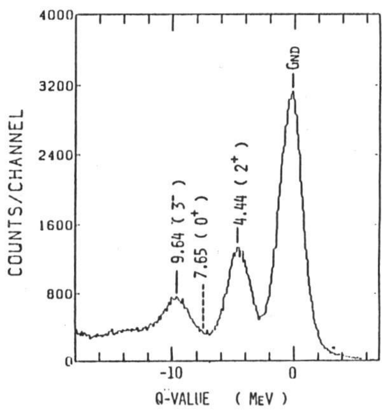


Fig. 6. (left up) Momentum spectrum measured by the tagging MWPC at FP1.

Fig. 7. (up) Separation of the second targets.

Fig. 8. (left) Q-value spectrum for the second scattering. This spectrum includes all the events included in Fig. 6 or Fig. 7.

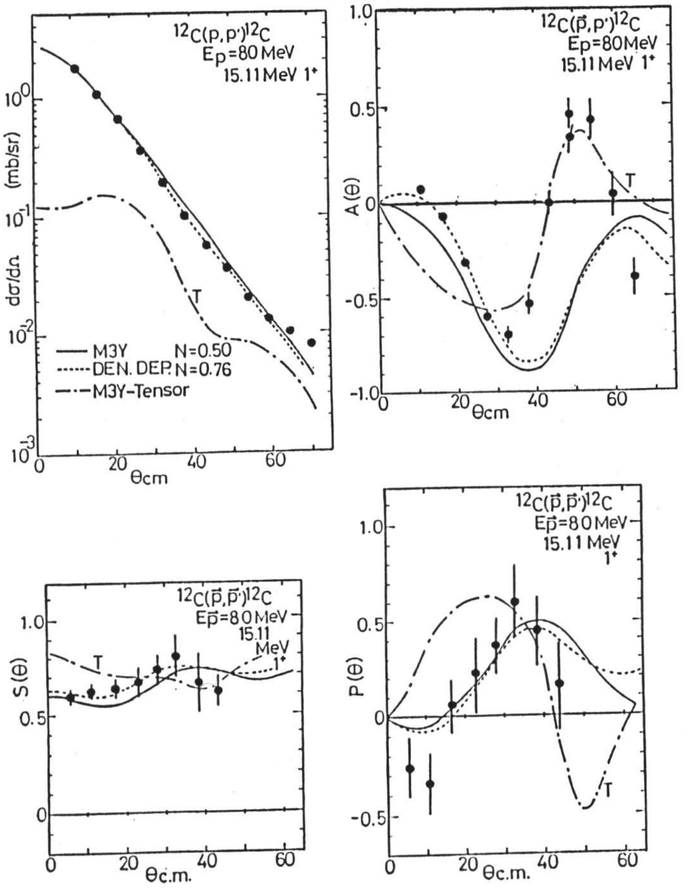


Fig. 9. Examples of data[9)]

Present addresses

*1 Sumitomo Heavy Industry Co. Ltd., Tokyo 101, Japan
*2 Institute of Physics, University of Tsukuba, Ibaraki 335, Japan
*3 Nara Women's University, Nara 630, Japan
*4 The Institute of Physical and Chemical Research, Wako, Saitama 351, Japan
*5 Sanyo Electric Co. Ltd., Osaka 573, Japan

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3) T. Noro et al., RCNP Annual Report 1984, p.191 and references therein.
4) M. Ieiri et al., contribution to this conference; RCNP Annual Report 1984, p.194 and references therein.
5) K. Hosono et al., contribution to this conference.

DISCUSSION

STEPHENSON: Have you considered measuring deuteron polarization with DUMAS?

NORO: No we have not. In order to measure deuteron polarization, we must reduce the thickness of the tagging counter and the second targets. Therefore it may be difficult to measure it efficiently.

SLOBODRIAN: What is the main contribution to the energy resolution that you showed?

NORO: When a primary beam is transported monochromatically, the main contribution to the resolution is aberration of magnetic system.