Recoil polarimetry in meson photoproduction at MAMI

M.H. Sikora[1)] D.I. Glazier[2)] D.P. Watts[3)]

(University of Edinburgh, King's Buildings, Edinburgh, EH9 3JZ, United Kingdom)

Abstract The nucleon excitation spectrum remains poorly known, with the masses, widths, EM couplings and even existence of many states not well established. A program of experiments using meson photoproduction off the nucleon is being carried out to improve this situation. A new large acceptance recoil polarimeter has been developed by the Edinburgh group for use in such reactions with the Crystal Ball at MAMI. This work summarizes the procedure used to measure recoil polarization with the new device and presents some preliminary results for the double polarization observable C_x in the reaction $\gamma p \rightarrow p\pi^0$, compared to the current partial wave analysis.

Key words polarimeter, meson photoproduction, polarization observable, recoil

1 Introduction

Various theoretical models of the nucleon give different predictions of its excitation spectrum. Many predicted resonances have not given signals in partial wave analyses of world data for meson scattering or photoproduction, or are inconsistently observed in different partial wave analyses[1]. The "missing" resonances may reflect insensitivities in previous measurements, or they may be due to inappropriate degrees of freedom in the models. The prospect of gaining insights into the spectrum from lattice QCD and holographic dual theories gives added current inputs to the field. The use of photon beams to study the excitation spectrum provides several experimental advantages: photons interact with the nucleon through the well understood electromagnetic interaction (QED), they can probe the entire nucleon volume, and they can be polarized. Experiments are being carried out at the major photon beam facilities (ELSA, JLAB, MAMI, GRAAL, LEPS) to provide additional constraints.

The nucleon excited states are studied by their decay via meson emission back to the ground state. Pseudoscalar meson production off the nucleon can be described theoretically by 4 helicity amplitudes[2, 3], leading to 16 experimental observables. These are the differential cross section, 3-single polarization observables corresponding to measurements of beam, target, or recoil polarization, and 12 double-polarization observables where simultaneous measurements of beam-target, beam-recoil, or target-recoil polarization are made. In order to fully constrain the reaction amplitudes and achieve a complete measurement, allowing a model independent analysis to be done, 8 observables must be measured. Crucially, these have to include measurements of double-polarization observables, including recoil polarization[3]. With this aim, the Edinburgh group has designed a large acceptance recoil nucleon polarimeter for use with the Glasgow/Mainz polarized photon beam and the Crystal Ball at MAMI.

2 Experimental facility

The Mainz Microtron is a 1.5 GeV racetrack electron accelerator. The circularly or linearly polarized photon beams are produced via bremsstrahlung when the electron beam is incident on an amorphous or crystalline radiator. The recoiling electrons are analyzed in a momentum spectrometer following the bremsstrahlung process. The measured difference between the incident and recoil momenta determines the photon energy with a resolution of ∼3 MeV.

Received 7 August 2009

1) E-mail: m.sikora@sms.ed.ac.uk
2) E-mail: dglazier@ph.ed.ac.uk
3) E-mail: dwatts@ph.ed.ac.uk

The main detector is the Crystal Ball (Fig. 1), a large acceptance (∼ 94% of 4π) calorimeter made of 672 NaI crystals. The angular resolution for photons is $\sigma_\theta \sim 2°—3°$ and $\sigma_\phi \sim 2/\sin\theta$. The TAPS detector, composed of 350 BaF_2 crystals, covers the forward region, $\theta <\sim 20°$. Identification of particles in TAPS uses time of flight, pulse shape discrimination, or ΔE techniques. The Particle Identification Detector (PID), a segmented barrel of 24 plastic scintillators surrounding the liquid hyrogen target at the center of the Crystal Ball, provides a ΔE signal for charged particles.

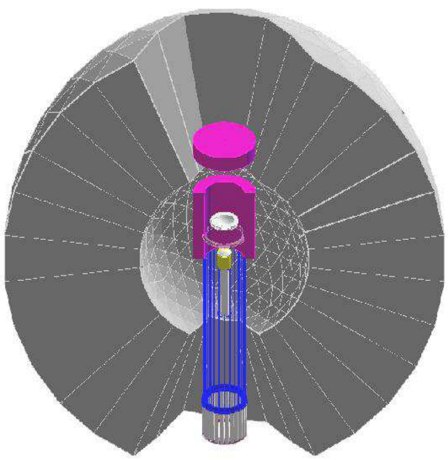

Fig. 1. Geant rendering of the polarimeter set up. Shown here are the target cell, the PID, the carbon scatterer, and the Crystal Ball.

3 Polarimetry

The polarization transferred to the recoiling proton from the photoreaction of interest is measured in a subsequent scatter reaction off a ^{12}C nucleus. The spin-orbit component of the nuclear interaction modulates the resulting azimuthal angular distribution of the nucleon according to

$$n(\phi_{\rm sc}) = n_0\left\{1 + A_{\rm eff}P_{\rm T}\sin(\phi_{\rm sc}+\phi_0)\right\}. \qquad (1)$$

which gives the number of protons scattered through the azimuthal angle $\phi_{\rm sc}$ as a function of the effective analyzing power $A_{\rm eff}$, the transverse polarization of the recoiling nucleon $P_{\rm T}$, and the total number of recoiling protons n_0.

A Geant rendering of the experimental set up is shown in Fig. 1. The PID is surrounded by a 2.5 cm thick carbon cylinder, and a carbon disc of the same thickness covers the forward direction. Determination of the scattering angles proceeds as follows: the 4-vector of the final state meson is measured from its decay to two photons by the Crystal Ball or TAPS. As the beam momentum is known, the direction of the recoil proton $\boldsymbol{r}_{\rm recon}$ into the carbon analyzer can be reconstructed. After scattering, the proton is detected in the Crystal Ball or TAPS, and the vector with respect to the center of the target is constructed ($\boldsymbol{R}_{\rm detector}$). The scattered proton vector is then obtained from

$$\boldsymbol{r}_{\rm sc} = \boldsymbol{R}_{\rm detector} - \boldsymbol{r}_{\rm recon}. \qquad (2)$$

The scattering axes are defined by the reconstructed proton momentum $\boldsymbol{p}$, the center of mass meson momentum $\boldsymbol{k}$, and the beam momentum $\boldsymbol{q}$ as $\hat{z} = \boldsymbol{p}/|\boldsymbol{p}|$, $\hat{y} = (\boldsymbol{k}\times\boldsymbol{q})/|\boldsymbol{k}\times\boldsymbol{q}|$, and $\hat{x} = \hat{y}\times\hat{z}$.

By periodically flipping the helicity of the photon beam, the aziumthal asymmetry in the resulting proton yields is fit to a sine function to determine the double polarization observable C_x, the degree of the polarization of the beam and the analyzing power transfered to the recoiling nucleon

$$\frac{n^+(\phi_{\rm sc}) - n^-(\phi_{\rm sc})}{n^+(\phi_{\rm sc}) + n^-(\phi_{\rm sc})} = C_x P_\gamma^{\rm circ} A_{\rm eff}\sin(\phi_{\rm sc}). \qquad (3)$$

C_x is then determined by dividing out the beam polarization and the effective analyzing power from the amplitude of the fitted sinusoid.

4 Data analysis

The first step of the analysis is to select events with a total of 3 hits in the Crystal Ball and TAPS. The two photons from the decay meson can be deduced by looping over the energy and momentum of all detector hits and calculating the invariant mass of each pair. Once the π^0 has been reconstructed, a cut is made on the missing mass of the proton (Fig. 2). An additional check in identifying pπ^0 events is made by comparing the ϕ angle of the π^0 with the ϕ angle measured in the PID of the recoiling proton before scattering in the graphite to ensure that the particles were back-to-back in the center of mass frame.

Once the reaction channel has been identified, protons which underwent a nuclear scatter in the graphite must be selected from the background scatters due to the Coulomb interaction. Fig. 3 graphs the scattering angle $\theta_{\rm sc}$ for the data and compares it with a Monte Carlo simulation with and without the hadronic interaction inclded. Up to about 13° Coulomb scattering is dominant, then falling off sharply, defining the region of useful scatters.

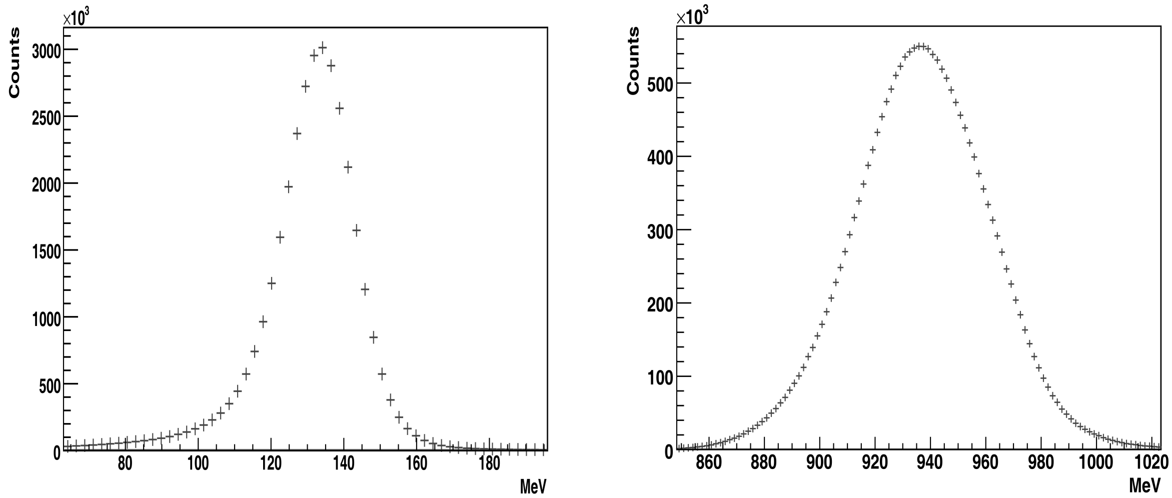

Fig. 2. Invariant π^0 mass and proton missing mass plots.

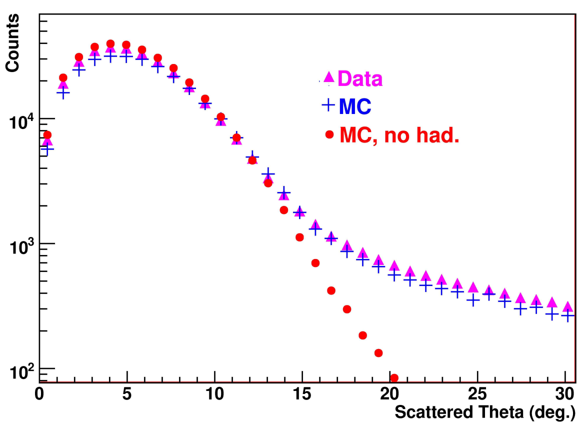

Fig. 3. Proton scattering angle in the polarimeter. Experimental data and MC simulations are identified by the key in the figure.

5 Analyzing power

We have developed our own parameterization of the pC analyzing power (Fig. 4) based on the world data set, which has been included in the Monte Carlo simulation. To extract a value for A_{eff}, events are simulated where the polarization of the recoiling protons is set to $+/-1$. The output is then analyzed using the same binning as for the data, and the resulting asymmetries fitted to a sinusoid, the amplitude of which is then divided out of the real asymmetries to extract C_x. The modelling of the analyzing power indicates that A_{eff} for the analysis is typically $\approx$0.2.

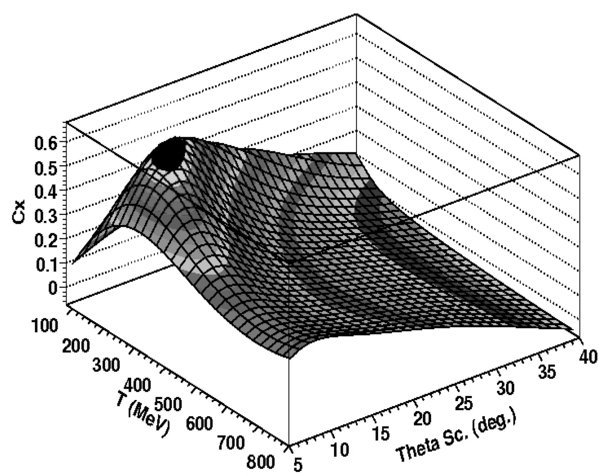

Fig. 4. Analyzing power as a function of kinetic energy and scattering angle.

6 Preliminary results

200 hours of data has been collected with the polarimeter using both linearly and circularly polarized photons. Preliminary results for C_x for the $p\pi^0$ channel are shown in Fig. 5 as a function of beam energy in 4 bins of center of mass θ. Our data points are shown alongside previous measurements from Jefferson Lab[4] and show reasonable agreement. The preliminary data are also compared with the results of a SAID partial wave analysis[5].

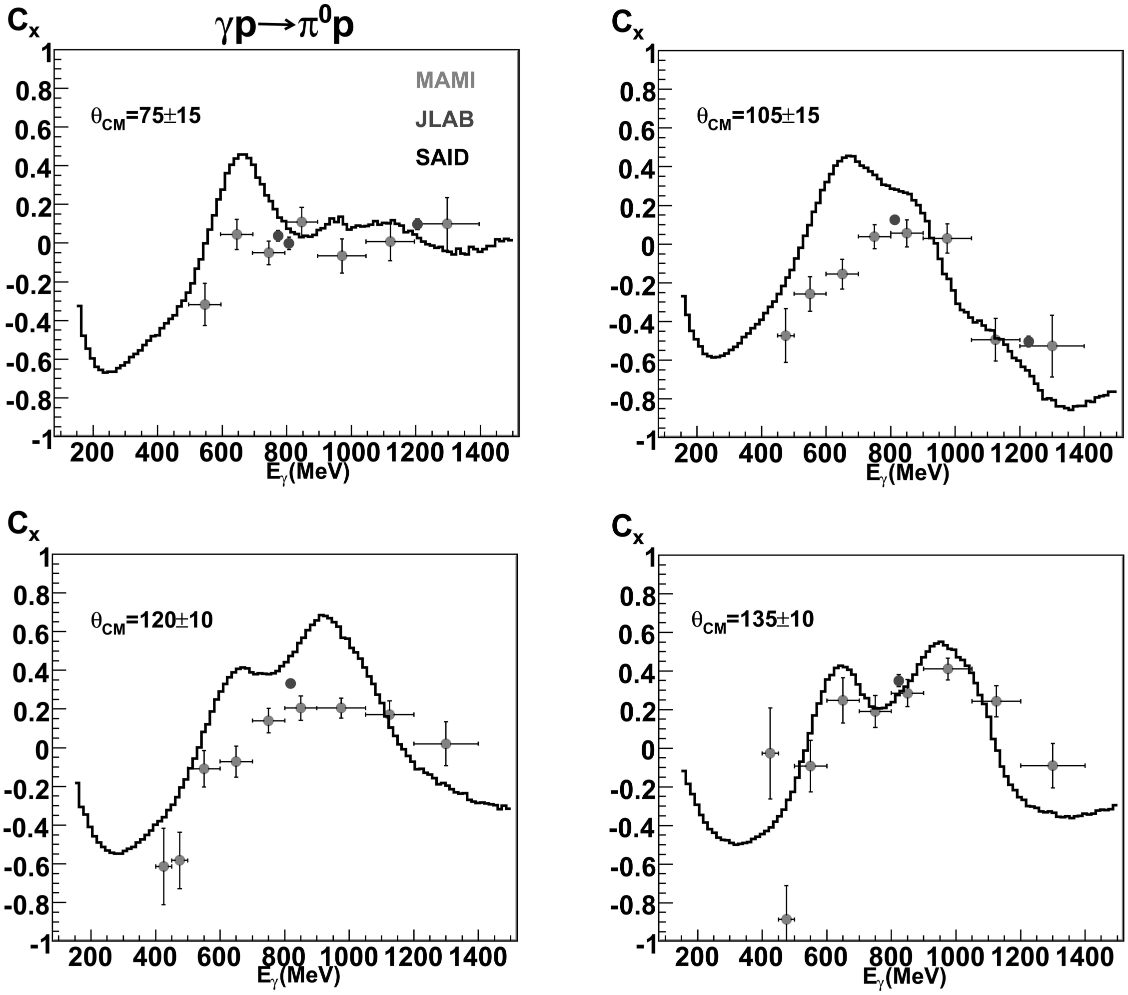

Fig. 5. Preliminary results for C_x. Our measurements are shown in red. The blue data are from a previous experiment done at Jefferson Lab.

7 Future plans

The analysis will be extended to the pη and pπ^0 π^0 channels, and the determination of the analyzing power will be finalized. The observables T (target asymmetry), P (recoil polarization), and O_x (beam-recoil with linear polarization) are also available in the existing data.

References

1 arXiv:0901.2055v1 [hep-ph]

2 Chew G F, Goldberger M L, Low F E, Nambu Y. Phys. Rev., 1957, **106**(6): 1345—1355

3 Barker I S, Donnachie A, Storrow J K, Nucl. Phys. B, 1975, **95**: 347—356

4 Wijesooriya K. Phys. Rev. C, 2002, **66**(3): 034614

5 http://gwdac.phys.gwu.edu/