MESON PHOTOPRODUCTION WITH LINEARLY POLARIZED γ-RAYS*

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(Received July 10, 2000)

The Graal experiment has measured various photoproduction processes off hydrogen in the nucleon resonance region. The simultaneous measurement of cross sections and beam asymmetries in a wide energy and angular range allows to extract with better precision the properties of the nucleon excited states. Results are presented for η, π^0 and π^+ photoproduction, and the impact in our knowledge of the barion spectrum is discussed.

PACS numbers: 25.20.Lj, 13.60.Le

1. Introduction

Various experiments are presently underway in order to obtain a more precise and complete knowledge of the baryon spectrum. Most of this new generation of measurements make use of high intensity and high polarisation electron and photon beams coupled with large acceptance detectors. The reason for this huge experimental effort is in the still unsatisfactory knowledge of the nucleon excited states. Predicted states are not sufficiently well established, and many properties of the observed states (*e.g.* coupling constants, branching ratios, helicity amplitudes) are often poorly known. The information contained in the table of baryon resonances [1] comes almost entirely from partial-wave analyses of pion–nucleon induced reactions. It is therefore necessary to deepen the study of baryon resonances by exploiting the features of the electro-magnetic probe (small coupling constant, easy polarisability of beams) in order to improve our knowledge of resonance properties.

* Presented at the Meson 2000, Sixth International Workshop on Production, Properties and Interaction of Mesons, Cracow, Poland, May 19–23, 2000.

Considering the simple case of pseudo-scalar meson photoproduction:

$$\gamma + p \rightarrow \mathrm{PS} + \mathrm{nucleon} \tag{1}$$

we can see that we have eight possible combination of spin states. The scattering amplitude is thus described by eight matrix elements only four of which are independent, due to rotational invariance and parity considerations.

With these four complex amplitudes, 16 bilinear products can be constructed, corresponding to 16 observables: the differential cross section, three single polarisation observables and twelve double polarisation observables. To completely determine the scattering amplitude, the cross section, the three single polarisation observables and four appropriately chosen double polarisation observables must be measured [2].

These observables can be adequately expressed in terms of helicity amplitudes. In that case, the following relations hold [3–5]:

$$\frac{d\sigma}{d\Omega} \sim H_1^2 + H_2^2 + H_3^2 + H_4^2 \,, \tag{2}$$

$$\Sigma \sim \mathrm{Re}\,(H_1 H_4^* - H_2 H_3^*) \,, \tag{3}$$

$$T \sim \mathrm{Im}\,(H_1 H_2^* - H_3 H_4^*) \,, \tag{4}$$

$$P \sim \mathrm{Re}\,(H_1 H_3^* - H_2 H_4^*) \,. \tag{5}$$

It is clear that the general structure of the scattering amplitude is contained in the differential cross section but its details are more clearly evidenced in the study of polarisation observables, where the interference among the helicity amplitudes can play a fundamental role in revealing more subtle effects [7].

The necessary experimental tools to perform part of the ambitious program of a full determination of the transition amplitudes are a completely and versatile polarised tagged photon beam, coupled with a large acceptance detector.

2. The Graal beam and the Lagrange apparatus

The Graal facility provides a polarised and tagged photon beam by the backward Compton scattering of laser light on the high energy electrons circulating in the ESRF storage ring [6]. Using the UV line (350 nm) of an Ar-ion laser we have produced a gamma-ray beam with an energy from 550 to 1470 MeV. Its polarisation is 0.98 at the maximum photon energy and the energy resolution has been measured to be 16 MeV (FWHM). Using the green line of the same laser we have measured the beam polarisation asymmetries and cross sections in the photoproduction of η [8] π^0 and π^+ [9] in the energy region 550–1470 MeV.

The Lagrange detector is formed by a central part surrounding the target and a forward part. Particles leaving the target at angles from 25° to 155° are detected by two cylindrical wire chambers with cathode readout, a barrel made of 32 strips of plastic scintillator parallel to the beam axis, used to determine the $\Delta E/\Delta x$ of charged particles, and the BGO rugby-ball made of 480 crystals of BGO scintillator.

The BGO ball is made of crystals of pyramidal shape with trapezoidal basis which are 21 radiation lengths long (24 cm). This calorimeter has an excellent energy resolution for photons [10], a good response to protons [11] and is very stable in time due to a continuous monitoring and calibration slow control system [12].

Particles moving at angles smaller than 25° encounter two plane wire chambers, (xy and uv) two walls of plastic scintillator bars 3 cm thin located at 3 m from the target point, that provide a measurement of the time-of-flight for charged particles (700 ps FWHM resolution) followed by a shower wall made by a sandwich of four layers of lead and plastic scintillators 4 cm thick that provides a full coverage of the solid angle for photon detection (with 95 percent efficiency) and a 20 percent efficiency for neutron detection.

Finally, two disks of plastic scintillator separated by a disk of lead complete the solid angle coverage in the backward direction.

The beam intensity is continuously monitored by a flux monitor, composed by three thin plastic scintillators and by a lead/scintillating fibre detector that measures energy and flux [13].

3. Results

The Graal experiment started data-taking in 1997 after six months of beam and apparatus commissioning during 1996. Two hydrogen targets were used, respectively three and six cm long. During 1997 the laser green line of 514 nm was used and a tagged photon beam, linearly polarised, was obtained with average intensity of 2×10^6 s^{-1} and energy between 550 and 1100 MeV. In 1998 the laser UV line of 351 nm was used. The corresponding backscattered beam had energy between 550 and 1470 MeV with typical intensity of 1×10^6 s^{-1}. The trigger was provided by the coincidence between the tagging counter and the detector trigger. The latter was initially formed only by requesting the total energy collected by the calorimeter to be larger than 160 MeV. Later a charged particles multiplicity trigger was added allowing forward events with small energy release in the calorimeter to be recorded. The rate of the DAQ was typically between 100 and 200 s^{-1}. During data taking, the polarisation of the gamma-ray beam was rotated, approximately every twenty minutes, by rotating the laser beam polarisation. Data were also collected without laser to obtain the contribution of the bremsstrahlung in the residual vacuum of the storage ring. The intensity of the bremsstrahlung beam was typically two orders of magnitude lower, with respect to the Compton beam.

3.1. η photoproduction

Since the isospin of η is $I{=}0$, the (γ,η) process offers the very attractive opportunity to study N^* resonances in a clean way, being insensitive to the propagation, in the intermediate state, of $I{=}3/2$ resonances, strongly coupled, *exempli gratia*, to the pion photoproduction channel. For this reason, the η photoproduction beam asymmetry and cross section were the first experiments analysed at Graal. The publication of the Σ beam asymmetry for η photoproduction [8] has stimulated a number of refinements in the existing theoretical approaches. Li and Saghai [14] investigate the process of η photoproduction within a quark model approach and find that significant contribution from $D_{13}(1520)$, $F_{15}(1680)$ and $P_{13}(1720)$ are required to reproduce the beam asymmetry data. Tiator and collaborators [16] have performed a combined analysis of η photoproduction cross section and asymmetry data. They have confirmed the role of $D_{13}(1520)$ and of $F_{15}(1680)$ and have extracted their ηN branching ratios. Mukhopadhyay and Mathur [17] have combined cross section [18] and single polarisation observables from Bonn (target asymmetry) [20] and from Graal, and by making use of an effective Lagrangian approach have extracted the electro-strong parameters

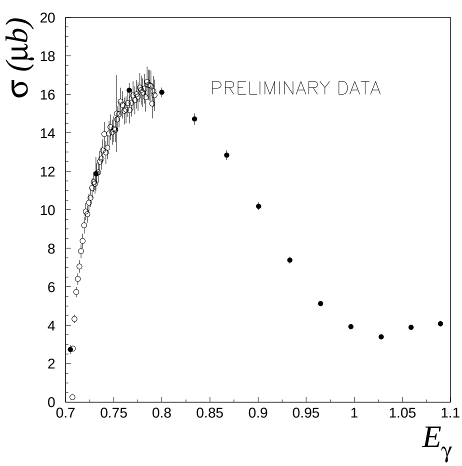

Fig. 1. Preliminary results on total cross section for η photoproduction on the proton (close circles) compared with the existing Mainz data set (open circles).

for the $N^*(1520)$ providing a critical test for many QCD inspired hadron models.

In figure 1 we show the preliminary results of the total η photoproduction cross section. There is an excellent agreement with the existing Mainz data [18] and the data set is now extended up to 1.1 GeV covering the full region of the $S_{11}(1535)$ resonance. The relevance of these results is discussed by Saghai and Li [19]. The increase of the cross section above 1 GeV cannot be reproduced by their chiral constituent quark approach.

3.2. Pion photoproduction

Pion photoproduction (π^0 and π^+) is one of the most extensively studied photoreaction and the main source of information on the structure of nucleons and nuclei. For this reason, a huge data base on differential cross section already exists but many of the measurements are not sufficiently accurate. The importance of the Graal contribution in this field lies in the excellent statistical and systematic error that is achieved and in the large energy and angular range covered by asymmetry measurements thus providing a new, consistent data base from 500 to 1500 MeV.

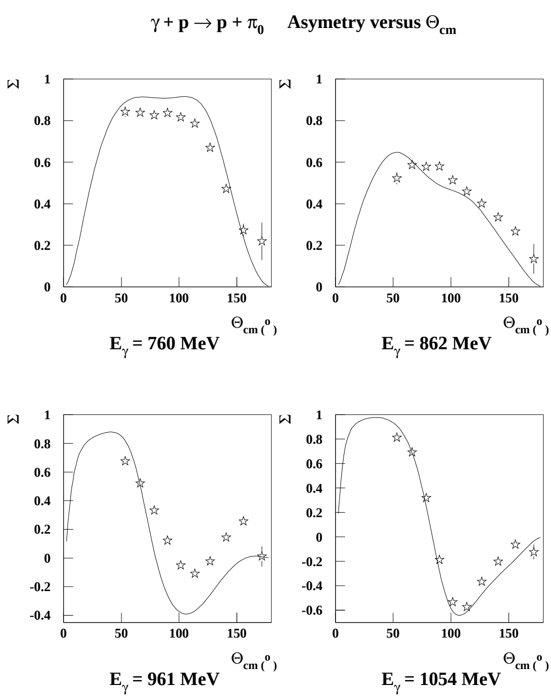

Fig. 2. Σ beam asymmetry for π^0 meson photoproduction on the proton

In figure 2 is shown a small sample of the collected and analysed data for Σ beam asymmetry in π^0 photoproduction. Data will soon be available from 500 to 1500 MeV. The curve shown is from Ref. [7]. We can see that the fine details of the asymmetry are only qualitatively reproduced: the small statistical error is a really strong constraint for all models and analyses.

In figure 3 the backward angles Σ beam asymmetry in π^+ photoproduction data are shown together with the existing old data from Daresbury [23] and SLAC [22]. The curves shown are from the partial wave analysis of the VPI group [21] (full curve) and from a recently developed isobar model by Drechsel and collaborators [15](dashed curve).

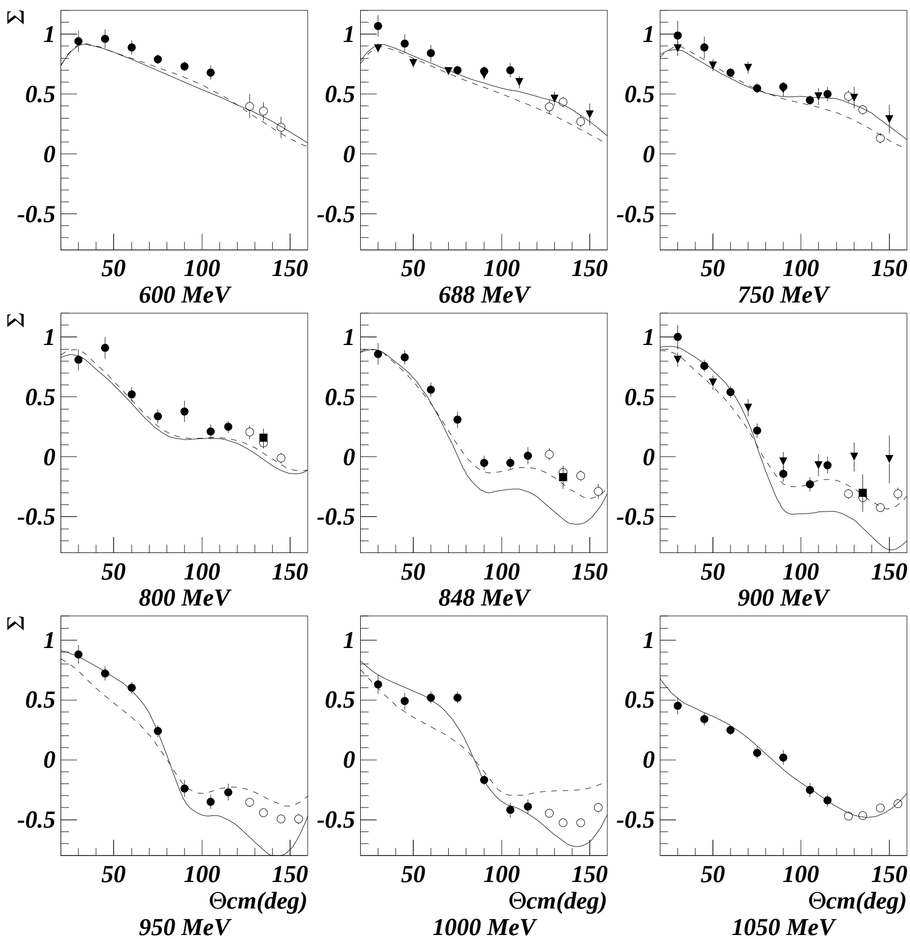

Fig. 3. Σ beam asymmetry for π^+ meson photoproduction on the proton. Open circles: Graal results, full circles: Daresbury, triangles and squares: SLAC.

4. Conclusions

The Graal experiment started data taking in 1997. It was run for one year with the green laser line giving rise to a photon beam of maximum energy of 1100 MeV and for one year with UV multi-line and the corresponding gamma-ray beam of 1470 MeV maximum energy. Asymmetry data and cross sections have been produced for η, π^0 and π^+ photoproduction channels providing, for these reactions, the most extended and coherent data base available until now. Beam asymmetries and cross sections for the photoproduction of 2 π^0, ω and $\eta^{'}$ will soon be extracted from the data already collected.

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