Meson photoproduction and baryon resonances at MAMBO experiment

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Abstract. Photoproduction of mesons within the framework of the MAMBO experiment (BGO-OD at Bonn plus MAMI at Mainz) was studied. The results on the operative work of the cryogenic $\text{H}_2/\text{D}_2$ target system during the last commissioning beam times at the March and June 2012 are shown. Investigation of the single charged pion photoproduction was provided using a polarized $\text{^3He}$ target at the tagged photon facility of the MAMI accelerator. Unpolarized and helicity dependent cross sections are presented for channels $\gamma N \rightarrow \pi^{\pm} X$ in the $\Delta(1232)$ baryon resonance region.

1. Introduction
During last 40 years Quantum Chromo Dynamics (QCD) established as the theory of the strong interaction. Perturbative approach could be used in the high energy regime, where the strong coupling constant is small, and in fact this approach has been successfully tested in several experiments. But in low energy regime, which is typical for nucleon and its excited states, it is not possible to use such approach because the strong coupling constant becomes large.

From the number of the effective degrees-of-freedom and their quantum numbers follow the number of the excited states with definite quantum numbers. The dominant decay mode of the nucleon resonances is hadronic decay via emission of mesons with a lifetimes typical for strong interactions $\tau \approx 10^{-24}s$ and a corresponding widths of a few 100 MeV [1]. Such a width together with spacing of the resonances not more than 10 MeV makes it difficult to investigate individual states, see Fig. 1.

For detailed tests of the quark models it is not enough studying of the excitation spectra (excitation energies and quantum numbers of the states). More information could be extracted from the transitions between the states which reflect their internal structure and are more sensitive to the model wave functions. Photoproduction of mesons is particularly interesting because the rich information connected to the electromagnetic transition amplitudes can be accessed in addition to the dominant hadronic decay modes [2].

In the present work the experimental test of nucleon models were performed in a two way. From one hand, the problem of the missing resonances could be studying by a large scale survey investigating many different final states – $N\pi$, $N\pi\pi$, $N\eta$, $N\eta'$, $N\omega$, $N\rho$ etc – over a large energy scale (BGO–OD). On the other hand, the low lying resonances can be studied in great detail providing data for precision tests of the models. The availability of linearly and circularly
Figure 1. Total photoabsorption cross section for reaction $\gamma N \rightarrow NX$; left side – on proton and right side – on neutron. Points are measured data, curves – fit of Breit-Wigner shapes of nucleon resonances $P_{33}(1232)$, $D_{13}(1520)$, $S_{11}(1535)$, $F_{15}(1680)$ (only for proton) and $F_{37}(1950)$ and a smoothly varying background [1].

polarized photon beams together with polarized targets has provided access to observables, which are sensitive to specific resonances (MAMI).

2. BGO–OD

The new experimental setup of the recently established BGO–OD collaboration consists of the combination of an open-dipole forward spectrometer and the BGO ball which cover the central angular region. This configuration is ideally suited to investigate the photoproduction of multi-particle final states with mixed charges. In addition it will allow nucleon polarization measurements in single-meson photoproduction. Due to the excellent forward acceptance it opens the possibility to investigate vector-meson production in order to understand the reaction mechanism and the role of resonances. The BGO–OD collaboration presently includes individuals and groups from Germany (Bonn), Italy (Rome, Frascati, Pavia, Messina), Russia (Gatchina, Moscow), UK (Edinburgh, Glasgow) and Ukraine (Kharkov). The experimental setup (see Fig. 2) consists of a large 90 ton dipole magnet, tracing detectors, two scintillating fiber detectors, MOMO and SciFi2 (to allow for momentum reconstruction of charged particles bent through the magnetic field), an aerogel Cherenkov detector (discriminates pions against protons and particularly improves the K-identification substantially), a time-of-flight (TOF) detector (provides flight-time measurements for charged particles and neutrons), the BGO Ball which is optimized for photon detection, good performances with protons (energy and angle reconstruction) and good neutron detection efficiency. BGO hermetically enclosing the target (polar angular range 25–155 degrees). Main features of BGO–OD beam: beam energy $E_\gamma = 0.7 – 2.8$ GeV; linear polarization degree up to 2.0 – 2.2 GeV; high intensity ($10^7 \gamma/s$) for low cross section reactions [3].

The Quantumcooler Hydrogen/Deuterium is a two stage closed-cycle refrigerator. The working fluid in all stages is an high purity helium gas. The nominal operating temperatures of each stage is 70 K and 20 K, respectively. Both stages are based on the Gifford-McMahon (G–M) cycle. The target cell is a 3 cm diameter aluminum cylinder, closed by thin mylar windows at the two sides. Two different lengths of the cell 6 cm and 11 cm are available. The target cell could be filled with liquid Hydrogen ($H_2$) or Deuterium ($D_2$). The hydrogen/deuterium gas is
cooling down by the helium through heat exchangers and liquefied inside the cell.

**Figure 2.** Overview of the experimental set up of the BGO–OD experiment

Starting from room temperature the target started to fill after 5 hours and full normally after 8 hours. To empty/fill cell is possible not only by “hand” changing the temperature of heater from 18 to 25 K, but also by remote, using the “slowcontrol” software. This process can be conveniently monitored by observing the $H_2$ tank pressure which varies from +0.9 bar (1.9 bar absolute) with the target empty to +0.74 bar (1.74 bar absolute) with the target full, see Fig.3.

**Figure 3.** Pressure on the gas tank during empty/refill process, 0.9 bar corresponds to the empty cell, 0.74 bar — to the full with liquid Hydrogen cell.
This has allowed in March and June 2012 to perform preliminary data taking for the commissioning of the BGO calorimeter, studying the $\pi^0$ and $\eta$ photoproduction on the proton and comparing the results for full/empty target. First results on the two–photon invariant mass have shown the detection of the $\pi^0$ and $\eta$ decay inside the BGO calorimeter. Further refinements are required on the beam collimation which still shows a strong background contamination.

3. MAMI

Another important subject in study of the baryon resonances is helicity dependent variables (especially on neutron), which provide better understanding of the reaction mechanism and structure effects. $^3$He is a system consisting of two protons with spins paired off and an active unpaired neutron, in relative $s$ state with 90% probability. As a result, magnetic moment of $^3$He can be approximated as the magnetic moment of the neutron: $\mu_{^3He} \approx \mu_n$.

During July, 2009 a first measurement of the double polarized photoabsorption cross section on $^3$He in the $\Delta(1232)$ baryon resonance region has been performed at the tagged photon facility of the MAMI accelerator in Mainz. Circularly polarized photons were obtained by bremsstrahlung of longitudinally polarized electrons with an average polarization of 75%, the bremsstrahlung photons were tagged using the Glasgow-Mainz magnetic spectrometer (energy resolution $\sim 2$ MeV). The relative tagging efficiency was monitored by a CCD photon camera and absolute measurements were made using a lead-glass detector. The reaction products were detected by the central detector system (see Fig. 4) consisting of the Crystal Ball (CB) NaI spectrometer, complemented by the Multi-Wire Proportional Chambers (MWPCs), used to identify and track the charged particles, and the cylindrical Particle Identification Detector (PID), used to distinguish the charged from the neutral particles detected by the CB. The combined information provided by these three detectors provides accurate energy, angle and particle identification in the azimuthal ($\phi$) and polar ($\theta$) angular regions from 0° to 360° and from 21° to 159°, respectively.

Figure 4. Side view of the central detectors setup [4]

Results and conclusions

Using dE/dx vs E technique, PID and MWPCs information pion/proton separation has been done. Preliminary results for the unpolarised and polarised differential cross sections of the $\gamma^3$He $\rightarrow \pi^\pm X$ reactions are presented in Fig. 5, 6. The data are compared to the predictions from Fix–Arenhoevel model [5] that take into account nuclear effects, such as FSI, and to the MAID model, where the nucleons inside the nucleus are assumed to be free and only the effect
of the spin alignments are taken into account. The polarised data are also compared to the DAPHNE data obtained on deuteron [6]. There is a good agreement for polarised differential cross sections between $^3He$ and deuteron data. The nuclear structure contributions are less important than for unpolarised case.

Figure 5. Preliminary results for the differential unpolarised cross section for the semi–inclusive channels $\gamma^3He \rightarrow \pi^\pm X$ for $E_\gamma = 361 - 483$ MeV. The experimental data (blue circles) are compared to the MAID model (dashed line) and Fix-Arenhoevel model (continuous red line).

Figure 6. Preliminary results for the helicity dependent differential cross section $\Delta \sigma$ for the semi–inclusive channels $\gamma^3He \rightarrow \pi^\pm X$ for $E_\gamma = 361 - 483$ MeV. The experimental data (blue circles) are compared to the MAID model (dashed line), Fix-Arenhoevel model (continuous red line) and DAPNE data [6] (red squares).

The present theoretical models are not able to describe in a satisfactory manner the experimental results. It is need to perform better description of the considered processes. Further measurements to improve statistics are needed.
References
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