FUTURE EXPERIMENTS AT MAMI WITH THE CRYSTAL BALL DETECTOR

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A new set of experiments on meson photoproduction up to $E_\gamma = 1.5$ GeV is being planned for MAMI-C. It extends to higher energies the program carried out at MAMI-B. The experimental apparatus consists of the Crystal Ball multiphoton spectrometer together with TAPS as a forward wall, a central tracker based on a cylindrical wire chamber, and a scintillator barrel. This configuration provides a geometrical acceptance approaching 4π sterad and has good energy and angular resolution for photons as well as good angular resolution for charged particles. The detector will be equipped with a frozen-spin polarized target filled with $^1\vec{\mathrm{H}}$, or $^2\vec{\mathrm{H}}$. The new experimental program will focus on the helicity dependence of partial channels for investigating the properties of baryon resonances. We are also considering the possibility of measurements using a polarized $^3\vec{\mathrm{He}}$ target. It will substantially improve the quality of the existing neutron data.

A new experimental program started at the Mainz Microtron Facility in spring 2004. The program is designed to study basic properties of hadrons using the MAMI photon beam. An incomplete list of currently approved experiments include: (i) first-ever measurement of the magnetic dipole moment of $\Delta^+(1232)$, $\mu(\Delta^+(1232))$, using the $\gamma p \to \gamma\pi^0 p$ reaction, (ii) a new, precise measurement of the η mass, (iii) measurements of branching ratios/upper limits for various rare and forbidden η decays, (iv) measurements of the photon asymmetry in π^0 photoproduction at threshold, (v) new, high statistics, full acceptance measurements of $\pi^0\pi^0$ photoproduction from protons and nuclei with linearly and circularly polarized beams, (vi) coherent π^0 production from nuclei. This program of precision photonuclear physics experiments becomes possible by combining a nearly 4π–acceptance experimental apparatus with a high quality tagged, polarized photon beam.

The maximum photon energy available with MAMI-B is E_γ^{max} =820 MeV. The resolution of the MAMI/Glasgow tagging facility [1] for bremsstrahlung photons is $\Delta E_\gamma = 2$ MeV for an incoming electron

beam of 855 MeV. The resolution can be improved at least by a factor of three using the tagger microscope. The microscope covers approximately 80 MeV of the photon bremsstrahlung spectrum. The maximum photon flux is $N_\gamma^{max} = 5 \times 10^5$ [s^{-1} MeV^{-1}], which is much higher than most other facilities. The degree of photon polarization is 70% for linearly and 85% for circularly polarized photons.

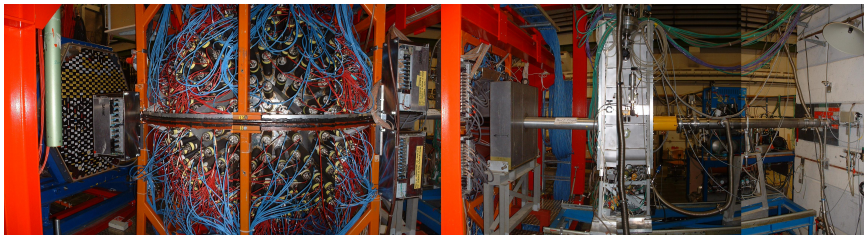

Figure 1. The experimental setup installed at the MAMI real photon beam. The Crystal Ball detector can be seen in the middle of the photo. The TAPS forward wall is close to the left. Part of the beam vacuum system and the refrigerator of the liquid hydrogen target are seen on the right side.

The setup assembled and tested for the photon beam has the following major components: (i) The Crystal Ball multiphoton spectrometer as the central detector. The spectrometer consists of 672 optically isolated NaI(Tl) crystals, 15.7 radiation lengths thick. The counters are arranged in a spherical shell with an inner radius of 25.3 cm and an outer radius of 66.0 cm. Each crystal is shaped like a truncated triangular pyramid, 40.6 cm high, pointing towards the center of the Ball. Electromagnetic showers in the spectrometer are measured with an energy resolution $\sigma_E/E \sim 1.7\%/(E\ (\mathrm{GeV}))^{0.4}$; the angular resolution for photon showers at energies of 0.05–0.5 GeV is $\sigma_\theta = 2°$–$3°$ in the polar angle and $\sigma_\phi = 2°/\sin\theta$ in the azimuthal angle, see Refs. [2,3] for details. (ii) The TAPS detector as a forward wall. TAPS [4] consists of 509 individual barium fluoride (BaF_2) crystals. The crystals are hexagonally shaped with an inscribed diameter of 59 mm and are 250 mm long (12 radiation lengths). In front of each crystal is a hexagonal plastic scintillator providing fast trigger information for charged particles. (iii) DAPHNE–type cylindrical wire chamber. Two coaxial cylindrical multiwire proportional chambers (MWPC) developed for the DAPHNE large-acceptance tracking detector [5] will be used as a central tracker. The chamber provides a track reconstruction efficiency of $\sim 85\%$ for $\pi^\pm$, and $\sim 90\%$ for protons. The resolution for the polar and

the azimuthal angles is a function of the polar angle and is expected to be $\Delta\Theta$(FWHM) $\lesssim 2^\circ$ and $\Delta\phi$(FWHM) $\lesssim 4^\circ$. (iv) A barrel of 24 narrow scintillator strips inside the wire chamber (PID) will be used for the purpose of particle identification. The apparatus provides good energy and angular resolution for photons and electrons as well as angular resolution for charged and neutral hadrons.

A Harmonic Double Sided Microtron (HDSM) is presently under construction to increase the output energy of the three staged Race-Track Microtron (RTM) cascade MAMI. The energy upgraded machine (MAMI-C) will provide E_γ^{max} =1.5 GeV, which corresponds to $\sqrt{s}$ = 1.92 GeV. This new accelerator is scheduled to come into operation in 2005. The new machine will substantially expand our research capabilities. In the second stage of the experiment we plan to measure, for example, the magnetic moment of the $S_{11}(1535)$, $\mu(S_{11})$, using $\gamma p \to \eta\gamma' p$, investigate π^0, η, ω, $2\pi^0$, etc. photoproduction on protons and neutrons, study rare decays of the η and η' to test chiral perturbation theory and C and CP invariance, obtain data for the threshold hyperon production on p and d targets.

A new Bonn-type frozen-spin polarized target [6] is under constriction in Mainz. The target has longitudinal polarization around 85 % for hydrogen and about 65 % for deuterium. Its horizontal cryostat is ϕ symmetric and allows measurements at $\Theta_{lab} < 160^\circ$. The cryostat designed to be used with 4π detectors fits into the Crystal Ball tunnel providing almost perfect ϕ symmetry for polarization measurements. The new target will be operational in late 2006. We also consider using a polarized ^{3}He gas target while waiting for the frozen-spin target. The polarized targets will be used for a series of measurements of the helicity dependence of partial photoproduction channels and their contribution to the GDH sum rule. We will concentrate on multipion final states such as $\pi^0\pi^0$, $\pi^0\pi^+$, $\pi^0\pi^0\pi^0$ produced on polarized hydrogen and deuterium.

The first production run of the CB@MAMI program, a measurement of the photon asymmetry in π^0 photoproduction at threshold, was accomplished in July–August 2004. Currently we are in the process of taking data for the measurements of the $\Delta^+(1232)$ magnetic dipole moment. Figures 2–5 illustrate the quality of the data, showing the most characteristic distributions. The invariant mass of two photons for an incident beam with energy above 700 MeV is shown in Fig. 2. The two peaks of the spectra are due to the reactions $\gamma p \to \pi^0(\gamma\gamma)p$ and $\gamma p \to \eta(\gamma\gamma)p$. The two–gamma invariant mass is shown for events with the missing mass equal to the mass of the proton. Figure 3 shows an excitation function of $\gamma p \to \eta(\gamma\gamma)p$ in

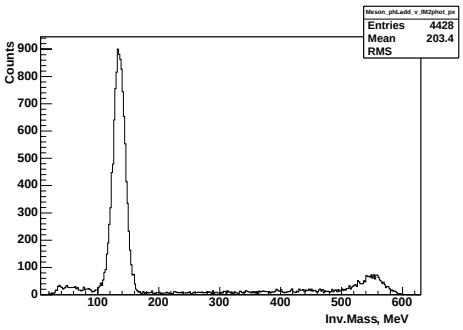

Figure 2. Invariant mass of two-cluster events for beam photons with energy above 700 MeV after requiring the missing mass to be equal to the mass of proton. The peaks are due to $\pi^0 \to 2\gamma$ and $\eta \to 2\gamma$ decays.

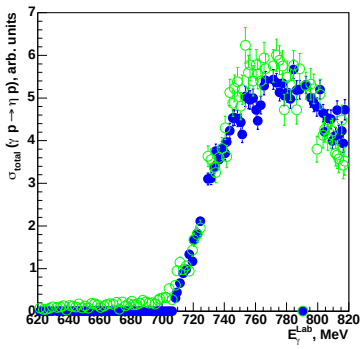

Figure 3. The total cross section of $\gamma p \to \eta p$ in arbitrary units from $\eta \to 2\gamma$ decay modes (solid circles) is compared to the $\gamma p \to 3\pi^0 p$ total cross section (open circles). Above the η threshold the $\gamma p \to 3\pi^0 p$ is mainly from $\eta \to 3\pi^0$ decay. The total cross sections are relatively normalized at $E_\gamma = 730$ MeV.

arbitrary units. The total cross section for $\gamma p \to 3\pi^0 p$ is shown on the same figure for comparison. Below η threshold $3\pi^0$ events are produced via sequential decay of resonances, while above the η–threshold most of the events are produced by the $\eta \to 3\pi^0$ decay. The two distributions are normalized at $E_\gamma = 730$ MeV.

The experimental setup made up of the Crystal Ball and TAPS is almost perfectly ϕ–symmetric. Together with the good quality polarized MAMI beam it allows high statistics, low systematics uncertainty, polarization measurements. Figure 4 shows the ϕ dependence of the beam photon asymmetry, $\Sigma(\phi)$, for the reaction $\gamma p \to \pi^0 p$. The asymmetry is not corrected for the beam polarization. The data represent about 5 % of the statistics obtained in the course of our most recent $\mu(\Delta(1232))$ run. The photon asymmetry as a function of $cos\Theta_{\pi^0}$ is shown in Fig. 5 for beam photon energies of 375 MeV, 405 MeV, and 436 MeV in comparison with MAID [7]. The results are very preliminary. The measured distributions are not corrected for the beam photon polarization; therefore, the MAID curves are normalized to the data at $\cos\Theta_\pi = 0$. The photon asymmetries obtained in our experiment show good agreement with the MAID evaluations for $\cos\Theta_\pi > 0$ and slightly deviate at backward angles. The difference between our data and MAID gets larger at higher beam energies.

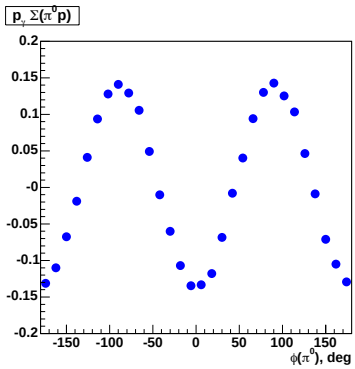

Figure 4. ϕ-dependence of the beam photon asymmetry times polarization, $p_\gamma \times \Sigma(\phi)$, for the reaction $\gamma p \to \pi^0 p$, where $\Sigma(\phi) = \frac{\sigma_\parallel(\phi)-\sigma_\perp(\phi)}{\sigma_\parallel(\phi)+\sigma_\perp(\phi)}$. The function shows clear $\cos(2\phi)$ behavior over the full angular range. The data covers the beam energy interval of 360–450 MeV and integrated over Θ_{π^0}.

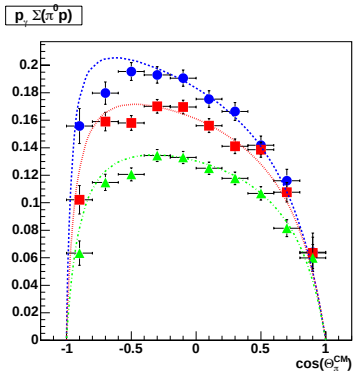

Figure 5. Preliminary results for the photon asymmetry times beam polarization shown as a function of $\cos\Theta_{\pi^0}$ in the c. m. for E_γ =375 MeV (triangles), 405 MeV(squares), and 436 MeV (circles), compared to MAID predictions. The MAID curves are normalized to the experimental data at $\cos\Theta_\pi = 0$.

A program of unique photonuclear physics becomes possible when combining a nearly 4π experimental apparatus with tagged, polarized photon beams and polarized p and d targets. Such a high-powered facility will allow first-ever measurements of the magnetic dipole moment of the charged and likely the neutral $\Delta(1232)$ and $N(1535)S_{11}$ resonances, measure meson photoproduction on a neutron target, threshold strangeness photoproduction, GDH on the neutron, a variety of double polarization ($\vec{\gamma}\vec{p}$) measurements, and more. Our first measurements with E_γ^{max} = 820 MeV MAMI-B beam took place in Summer-Fall 2004. We plan to start the next stage of the experimental program with the 1.5 GeV MAMI-C beam by the end of 2005. The frozen-spin polarized target is under construction.

References

1. I. Anthony *et al.*, Nucl. Instrum. Methods **A 301**, 230 (1991).
2. A. Starostin *et al.*, *Phys. Rev.* **C64**, 055205 (2001).
3. S. Prakhov *et al.*, *Phys. Rev.* **C69**, 045202 (2004).
4. R. Novotny, IEEE Trans. Nucl. Sci. A **38**, 379 (1991).
5. G. Audi *et al*, Nucl. Instr. and Meth. **A301**, 473 (1991).
6. C. Bradtke *et al*, Nucl. Instr. and Meth. **A436**, 430 (1999).
7. D. Drechsel, S.S. Kamalov, L. Tiator, Nucl. Phys. A645, 145 (1999).