Real Photon Experiments with a
Transverse Polarized Target at MAMI

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Abstract. The A2-collaboration at the Mainz Microtron MAMI is measuring photon absorption cross section using circularly and linearly polarized photons up to the energy of 1.5 GeV. The photons are produced in the ‘Bremsstrahlungs’ process. In the years 2005/2006 the Crystal Ball detector with its unique capability to cope with multi photon final states was set up in Mainz. Since 2010 the experimental apparatus has been completed by a polarized target. The horizontal dilution refrigerator of the Frozen-Spin Target has been constructed and is operated in close cooperation with the Joint Institute for Nuclear Research in Dubna, Russia. The system offers the opportunity to provide longitudinally and transversely polarized protons and deuteron. In this paper experiments with the transversely polarized Frozen-Spin Target that was used for the runs in 2010 and 2011 are discussed.

1. Introduction

Since more than 20 years the international A2 collaboration has been measuring photo absorption cross sections of circularly polarized photons on unpolarized and polarized protons and deuterons to determine the total cross section and partial reaction channels in a large kinematical range, which provides new information about the excitation spectrum of the nucleon. The A2-Glasgow-Mainz tagging facility stands out due to its high photon intensity. In the framework of the GDH-experiment there was used a longitudinally polarised Frozen-Spin Target [1] from the University Bonn in combination with the DAPHNE detector. In the year 2010 a new Frozen-Spin Target, produced in collaboration with the Joint Institute for Nuclear Research, Dubna, Russia, came into operation and was used with transverse polarized protons and deuteron for more than 5000 hours in beam.

2. The A2 Real Photon Facility

The A2 Real Photon Facility is one of the three major experiments using the electron beam from the MAMI accelerator, see figure 1. The experiments A1 and A4 use the direct electron beam, while in A2 the electron beam is converted in a beam of photons in the ‘Bremsstrahlungs’ process.

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The MAMI accelerator with its source of polarized electrons, based on the photo-effect on a strained GaAs crystal, routinely delivers polarized beams with a maximum energy of 1608 MeV. We typically have a degree of polarization of about 85%. Details about the new machine type can be found in reference [1].

The electrons are used to produce a secondary beam of real photons in the ‘Bremsstrahlungs’ process. The energy of these photons is detected in the Glasgow-Mainz tagging-system [2]. The resulting photons can be circularly polarized, with the application of a polarized electron beam, or linearly polarized, in the case of a crystalline radiator. The degree of polarization achieved is dependent on the energy of the incident photon beam $E_0$ and the energy range of interest, but currently peaks at $\sim 75\%$ for linear polarization and $\sim 85\%$ for circular polarization.

The Glasgow Photon Tagger (see figure 2) provides energy tagging of the photons by detecting the post-radiating electrons and can determine the photon energy with a resolution of 2 to 4 MeV depending on the incident beam energy, with a single-counter time resolution of 0.117ns. Each counter can operate reliably to a rate of $\sim 1$ MHz, giving a photon flux of $2.5 \times 10^5$ photons per MeV. Photons can be tagged in the momentum range from 4.7 to 93.0% of $E_0$. 

**Figure 1.** Floor plan of the MAMI accelerator with experimental halls.
2.1. The detector system

The central detector system consists of the Crystal Ball calorimeter combined with a barrel of scintillation counters for particle identification and two coaxial multi-wire proportional counters for charged particle tracking. This central system provides position, energy and timing information for both charged and neutral particles in the region between $21^\circ$ and $159^\circ$ in the polar angle and over almost the full azimuthal range. At forward angles, less than $21^\circ$, reaction products are detected in the TAPS forward wall. The full, almost hermetic, detector system is shown schematically in figure 3. The full angular coverage of this detector system sets very rigorous condition for the construction of the polarized target.

The Crystal Ball detector (CB) is a highly segmented 672-element NaI(Tl), self triggering photon spectrometer constructed at SLAC in the 1970's. Each element is a truncated triangular pyramid, 41cm (15.7 radiation lengths) long. The readout electronics for the Crystal Ball were completely renewed in 2003, and it now is fully equipped with SADCs which allow for the full sampling of pulse-shape element by element. In normal operation, the onboard summing capacity of these ADCs is used to enable dynamic pedestal subtraction and the provision of pedestal, signal and tail values for each element event-by-event. Each CB element is also newly equipped with multi-hit CATCH TDCs. The readout of the CB is effected in such a way as to allow for flexible triggering algorithms. There is an analogue sum of all ADCs, allowing for a total energy trigger, and also an OR of groups of sixteen crystals to allow for a hit-multiplicity second-level trigger - ideal for use when searching for high multiplicity final states.

In order to distinguish between neutral and charged particles species detected by the Crystal Ball, the system is equipped with PID2, a barrel detector of twenty-four 50mm long, 4mm thick scintillators, arranged so that each PID2 scintillator subtends an angle of $15^\circ$ in $\phi$. By matching a hit in the PID2 with a corresponding hit in the CB, it is possible to use the locus of the $\Delta E, E$ combination to identify the particle species. This is primarily used for the separation of charged pions, electrons and protons.

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**Figure 2.** The A2 Glasgow/Mainz tagging system.
3. The Polarized target

The new Frozen-Spin target was designed to retain the high angular acceptance of the detector system. The main boundary condition for the outer diameter of the target cryostat was the most inner particle identification detector PID2 with a diameter of 104 mm. The internal holding coils had to be as thin as possible to allow particles to punch through.

The core of the Frozen-Spin target for the Crystal Ball detector is a specially designed, large, roughly 2m long, horizontal $^3$He/$^4$He dilution refrigerator (see figure 4) that was built in cooperation with the Joint Institute for Nuclear Research (JINR) Dubna.

The cryostat has a separator working at 3 K and an evaporator working at 1.2 K in the pre-cooling stages. These are pumped by rotary pumps with pumping speed of 60 m$^3$/h, 100 m$^3$/h and 250 m$^3$/h (company Busch). The beam axis is equal to the cryostat axis and the target material has to be loaded along the beam axis using a specially adapted, twofold target-insert. This target-insert needs to seal the cavity against the beam pipe vacuum. It has minimum limitations for the particle detection and fits into the central core of the inner Particle Identification Detector (PID2). This was achieved by using the Frozen-Spin technique in combination with the new concept of placing a thin superconducting holding coil on the thermal radiation protection shields of the refrigerator.

The cryostat could provide a very low operation temperature of 25mK in the target chamber. The butanol is filled into a PTFE-cylinder of 2cm length and diameter. A temperature stability of better than ±0.2mK over a time scale of a week was reached. This corresponds to very long relaxation times of the target nuclei in the order of some thousands of hours. Typically the target had to be re-polarized once a week. Longitudinal and transverse polarizations are possible.
Figure 4. The $^3$He-$^4$He dilution refrigerator.

3.1. The transverse holding coil

The transverse holding coil was designed as a 4-layer dipole magnet, allowing for high homogeneity. The coil was wound from a single wire to avoid soldering joints and to provide a high critical current.

Figure 5. The transverse holding coil.

The transverse coil has been in operation for more than 4000 hours in the years 2010 and 2011 at a current of 35 A, corresponding to a field of 0.45 Tesla. The current leads are optimized for low
thermal input: In the first step we enter into the cryostat with thick, normal conducting copper wire to a temperature of 70 K, next step high temperature superconducting band is used. The helium consumption for stable operation of the complete cryostat (target material at 25 mK and holding coil at 0.45 T) was below 2.5 liters per hour, showing a very economic design of all heat exchangers.

4. First Measurement of the T- and F-observables in π- and η-production

In the first measurement campaign with the new Frozen-Spin target we have used a circularly polarized photon beam in combination with transversely polarized protons and deuterons. The analysis is still preliminary [4] and final calibrations have to be done. Figure 6 from a recent publication on an unpolarized hydrogen target shows the quality of the data to be expected from our polarized measurements.

Figure 6. Total cross section for the reaction $\gamma\pi \rightarrow p\pi^0$.

5. References

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