ФИЗИКА ЭЛЕМЕНТАРНЫХ ЧАСТИЦ И АТОМНОГО ЯДРА
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THE NEW FROZEN-SPIN TARGET AT MAMI

A. Thomas[1], *N. S. Borisov*[2], *H.-J. Arends*[1], *A. N. Fedorov*[2], *G. M. Gurevich*[3], *R. L. Kondratiev*[3], *M. Korolija*[4], *A. B. Lazarev*[2], *M. Martinez*[1], *W. Meyer*[5], *S. V. Mironov*[2], *A. B. Neganov*[2], *V. N. Pavlov*[2], *H. Ortega*[1], *G. Reicherz*[5], *Yu. A. Usov*[2]

[1] Institut für Kernphysik, Universität Mainz, Mainz, Germany

[2] Joint Institute for Nuclear Research, Dubna

[3] Institute for Nuclear Research, Russian Academy of Sciences, Moscow

[4] Rudjer Boskovic Institute, Zagreb, Croatia

[5] Institut für Experimentalphysik I, Ruhr-Universität Bochum, Bochum, Germany

The new frozen-spin polarized target for experiments at the polarized beam of the real photon facility A2 of the MAMI accelerator is described. 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 «bremsstrahlung» process. In the years 2005/2006 the crystal ball detector with its unique capability to cope with multiphoton 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 deuterons. In this paper, the operation experience of this new frozen-spin target and first results from the runs in 2010 and 2011 are presented.

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1. THE «CRYSTAL BALL AT MAMI»

1.1. The MAMI Accelerator. The MAMI accelerator (see Fig. 1) with its source of polarized electrons, based on the photoeffect 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 [1].

1.2. 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 Fig. 2.

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 «bremsstrahlung» process. The electrons are used to produce a secondary beam of real photons in the «bremsstrahlung» process. The energy of these photons is detected in the Glasgow–Mainz tagging system [2].

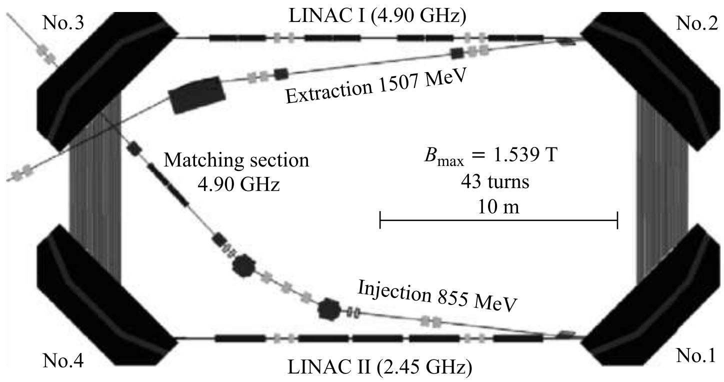

Fig. 1. The accelerator stage MAMI-C is realized as a Harmonic Double Sided Microtron (HDSM). Main features of this new machine concept are the four 90° bending magnets and the two LINACs working on 2.45 GHz and the first harmonic

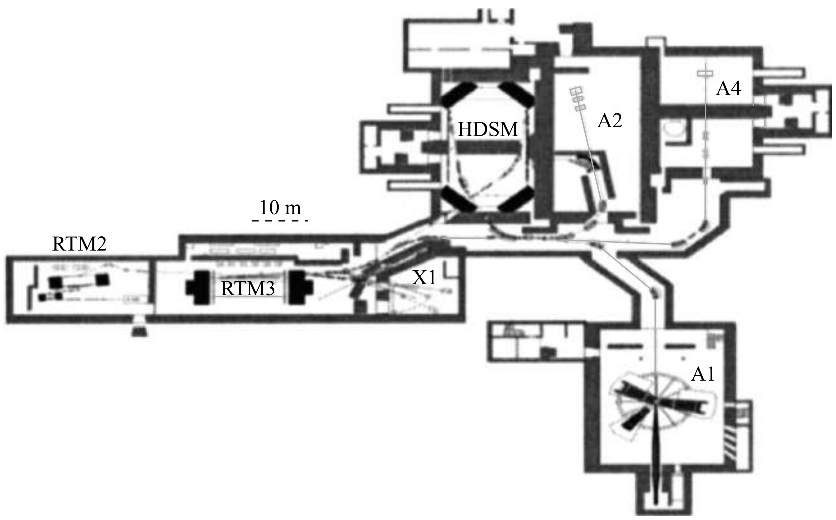

Fig. 2. Floor plan of the MAMI accelerator with experimental halls

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 Fig. 3) provides energy tagging of the photons by detecting the postradiating electrons and can determine the photon energy

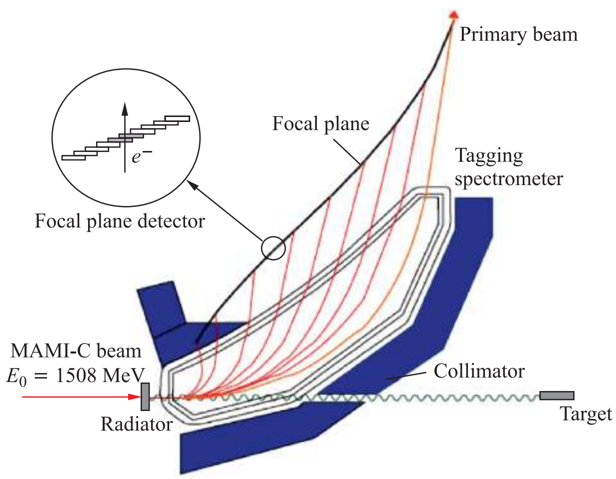

Fig. 3. The A2 Glasgow–Mainz tagging system

with a resolution of 2 to 4 MeV depending on the incident beam energy, with a single-counter time resolution of 0.117 ns. Each counter can operate reliably to a rate of ~ 1 MHz, giving a photon flux of $2.5 \cdot 10^5$ photons per MeV. Photons can be tagged in the momentum range from 4.7 to 93.0% of E_0.

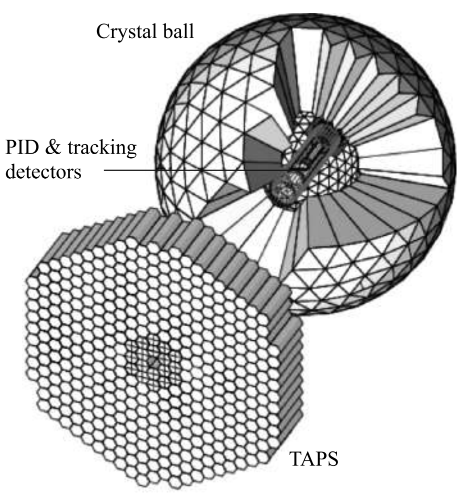

Fig. 4. The crystal ball calorimeter, with cutaway section showing the inner detectors, and the TAPS forward wall

1.3. The Crystal Ball Detector Setup. The central detector system consists of the crystal ball calorimeter combined with a barrel of scintillation counters for particle identification and two coaxial multiwire 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 and 159° in the polar angle and over almost the full azimuthal range.

At forward angles, less than 21°, reaction products are detected in the TAPS forward wall. The full, almost hermetic, detector system is shown schematically in Fig. 4. The full angular coverage of this detector system sets very rigorous condition for the construction of the polarized target.

2. THE POLARIZED TARGET

The main concept of this target is similar to that one of the Bonn frozen-spin target [3], which was used in 1998 and 2003 for the measurement of the GDH sum rule on the proton and neutron in Mainz [4–6]. 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 frozen-spin target cryostat was the most inner particle identification detector 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 horizontal ^{3}He/^{4}He dilution refrigerator (see Figs. 5 and 6) that was built in cooperation with the Joint Institute for Nuclear Research (JINR), Dubna.

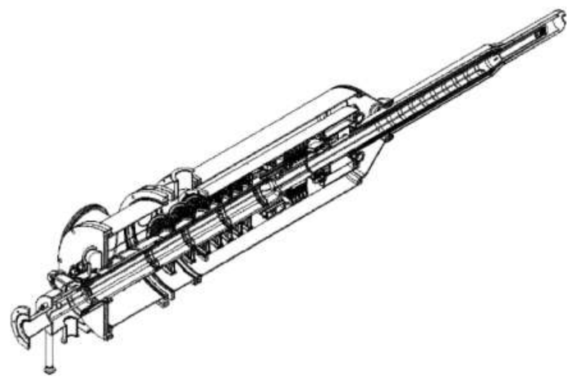

Fig. 5. 3D construction of the dilution refrigerator

Fig. 6. The dilution refrigerator with longitudinal holding coil

The cryostat has a separator working at 3 K and an evaporator working at 1.2 K in the precooling stages. These are pumped by rotary pumps with pumping speed of 60, 100, and 250 m^3/h (Busch company). 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 with the new concept of placing a thin superconducting holding coil on the thermal radiation protection shields of the refrigerator. Longitudinal and transverse polarizations are possible. For longitudinal polarization, a solenoid has to be installed, for transverse polarization a 4-layer saddle coil is needed, see Fig. 7.

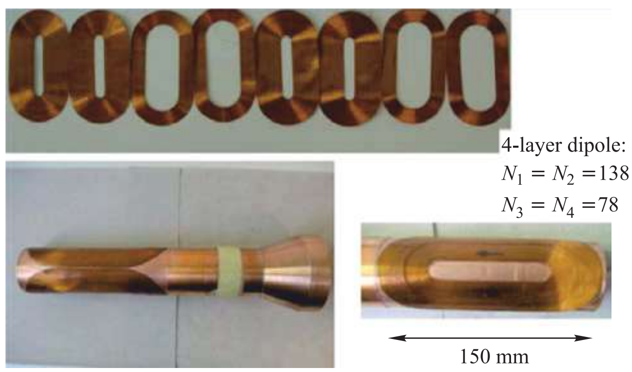

Fig. 7. The internal superconducting holding coils for transverse field operating at 1.2 K can be seen

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 T. 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, in the 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 l per hour, showing a very economic design of all heat exchangers.

The NMR system to measure the degree of target polarization is a serial resonance circuit with a coil within or around the target material. We have used TEMPO doped butanol and trityl doped deuterated butanol target substrates, provided by the Bochum polarized target group (Figs. 8 and 9).

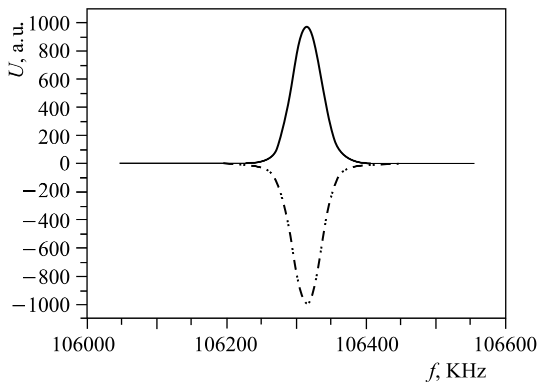

Fig. 8. NMR signals of highly polarized protons, positive polarization shown was $+83.6\%$, negative -81.5%

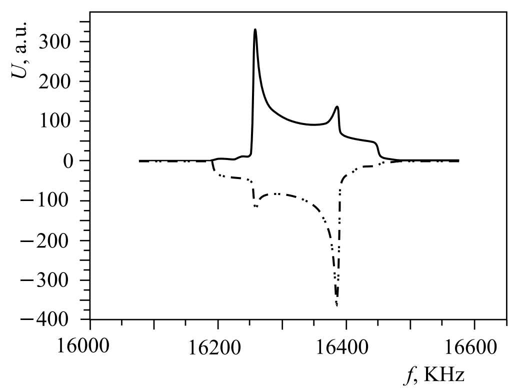

Fig. 9. NMR signals of highly polarized deuterium, positive polarization shown was $+75.9\%$, negative -75.2%

In conclusion, we have achieved the following target parameters:

— maximum total tagged photon flux in the energy range of 4.7 to 93% of E_0: $5 \cdot 10^7$ s^{-1}, with relaxation time of around 1500 h for protons and deuterons at a magnetic field of 0.45 T and a temperature of 25 mK;

— proton density in 2 cm cell: $N_T = 9.1 \cdot 10^{22}$ cm^{-2};

— average proton polarization $P_p = 70\%$;

— deuteron density in 2 cm cell: $N_T = 9.4 \cdot 10^{22}$ cm^{-2};

— average neutron polarization $P_n = 60\%$.

3. MEASUREMENT OF THE T- AND F-OBSERVABLES IN π- AND η-PRODUCTION

In the first measurement campaign with the new frozen-spin target in 2010 and 2011 we have used a circularly polarized photon beam in combination with transversely polarized protons and deuterons. The analysis is still preliminary and final calibrations have to be done. Figure 10 with our new points in red from the recent publication [7] on an unpolarized hydrogen target shows the quality of the data to be expected from our polarized measurements.

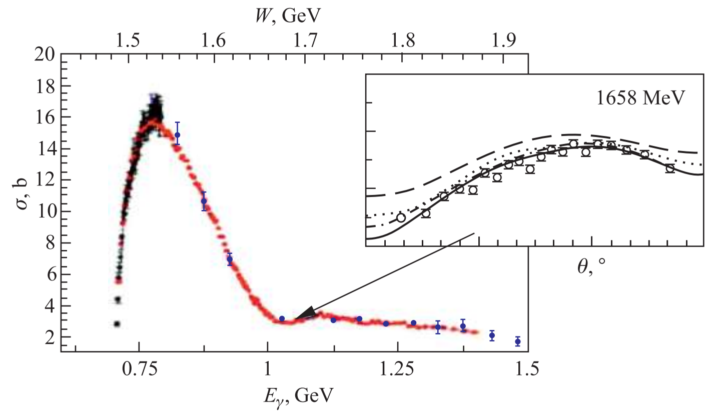

Fig. 10. (Color online) Total cross section for the reaction $\gamma\pi \to p\eta$

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