The Mainz Microtron MAMI

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Abstract. An overview of the Mainz Microtron MAMI is given. The main goal is to study the low-energy structure of hadrons. Typical examples are measurements of nucleon form factors, the polarizability of nucleons and pions and the detailed study of the excitation spectrum of nucleons. At present, an energy upgrade to 1.5 GeV (MAMI C) is close to completion. The status of the new accelerator section (HDSM) and experimental setups are briefly described and an outlook to the planned physics program is given.

PACS. 13.60.-r Photon and charged-lepton interactions with hadrons – 14.20.Dh Protons and neutrons – 14.14.Aq pi, K, and eta mesons

1 Introduction

The Mainz microtron MAMI is a unique facility in Europe to study the hadron structure with the electromagnetic probe at small momentum transfers. It consists in its present stage of three race track microtrons and delivers high quality polarized electron and photon beams with energies up to 885 MeV into the experimental halls, see Fig. 1. A recent comprehensive overview of the physics achievements in the past two decades is contained in Ref. [1]. A fourth stage, MAMI C, which will upgrade the energy to 1.5 GeV, is close to completion and is expected to go into operation at the beginning of 2007.

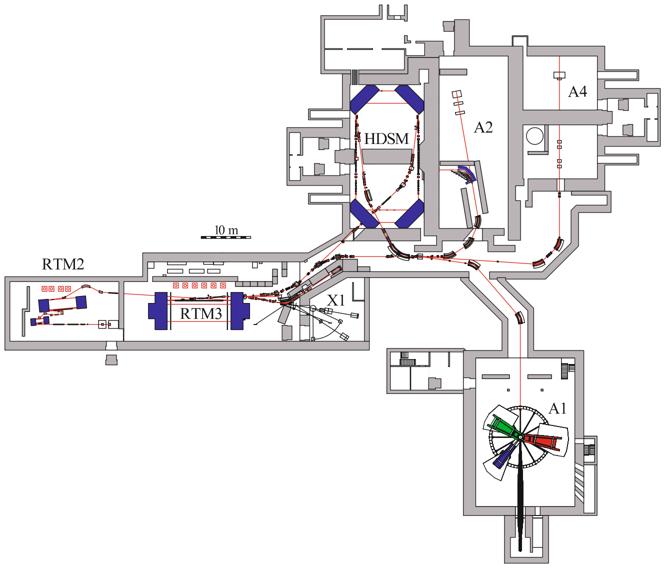

Fig. 1. Floor plan of the Mainz microtron MAMI, consisting of 3 racetrack microtrons and the new stage HDSM (harmonic double-sided microtron)for MAMI C. Also shown are the experimental areas A1, A2, A4, and X1.

2 Selected recent experiments

The experimental program at MAMI is focussed on studies of the hadron structure in the domain of non-perturbative QCD. In this sense we are dealing with the "many-body structure of strongly interacting systems", which is also the topic of our Collaborative Research Center SFB443. The main observables sensitive to the hadron structure are:

- the spatial distribution of charge and magnetization: electromagnetic form factors of the nucleon, measured via elastic electron scattering
- the response of the system to electromagnetic fields: polarizability of the nucleon and the pion, measured via photon scattering
- the excitation spectrum: resonance structure, investigated via photo- and electroexcitation.

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Examples for such fundamental investigations, where MAMI has made significant contributions in the recent years, are shown in Figs. 2 and 3. The MAMI measurements of the neutron charge form factor G_E^n (Fig. 2), together with the results from other laboratories, now gives a very consistent set of data [3]. While a fundamental theoretical interpretation is still missing, an intuitive interpretation leads to a picture, where the neutron behaves a considerable fraction of time as a proton with a surrounding negative pion cloud [4].

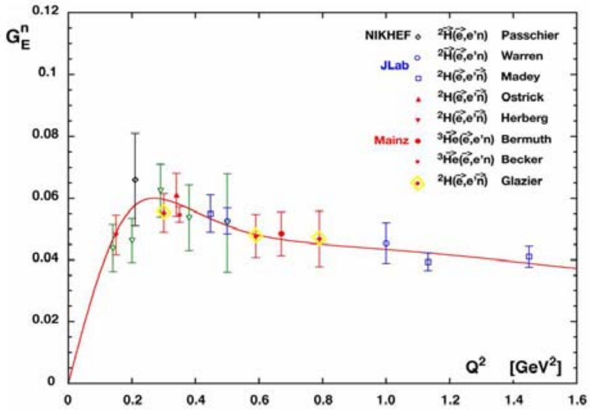

Fig. 2. Electric form factor of the neutron. Double-polarization data from Bates, NIKHEF, JLab, and MAMI are shown.

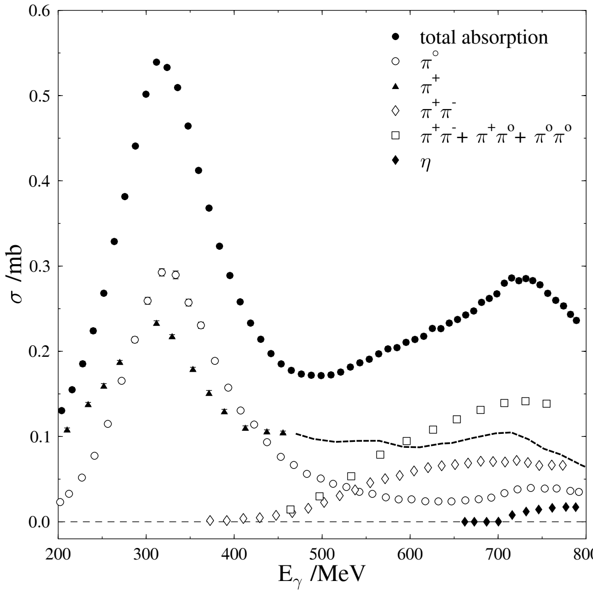

Fig. 3. Excitation spectrum of the proton. Data for total photo absorption and partial reaction channels from MAMI.

The excitation spectrum of the proton has been studied at great detail at MAMI using tagged photons. Figure 3 shows the total photo absorption cross section together with all partial reaction channels accessible in this energy range. Besides the cross sections a wealth of polarization observables has been measured at high precision [5,6].

3 Experimental equipment

Dedicated experimental tools have been developed for these investigations. The A1 Collaboration uses a set of three magnetic spectrometers (Fig. 4) with a momentum resolution of about 10^{-4} and solid angles of 5,6 and 28 msr.

The A2 Collaboration uses a tagger to produce energy-labelled real photons and the Crystal Ball/TAPS detector (Fig. 5). The Crystal Ball is a photon spectrometer consisting of 672 NaI crystals, the forward wall (TAPS) is an arrangement of BaF_2 crystals. Both systems are ideally suited for multiple-photon detection. Figure 6 shows the invariant mass distribution for 2γ events. Tracking information for charged particles is given by wire chambers and scintillation counters surrounding the target. In 2004/05 the detector system has successfully taken high-statistics data to study the magnetic dipole moment of the $\Delta^+(1232)$, threshold production of single and double π^0, η production (η mass and rare η decays), helicity asymmetry and medium modification of double-pion production, and others. The data are presently being analyzed.

Fig. 4. A photograph of the three high-resolution spectrometers in the A1 hall.

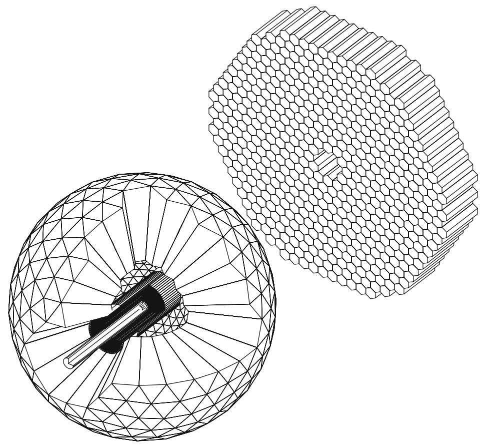

Fig. 5. The Crystal Ball detector with TAPS as forward wall. Tracking information for charged particles is provided by inner wire chambers and scintillation counters.

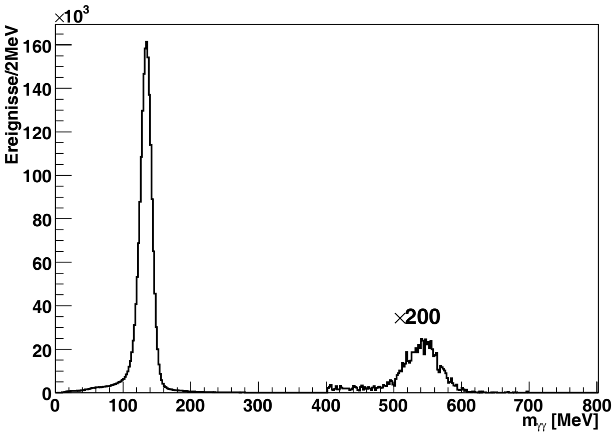

Fig. 6. Invariant mass for 2γ events with an additional proton identified. The peaks are due to $\pi^0 \to 2\gamma$ and $\eta \to 2\gamma$ decays.

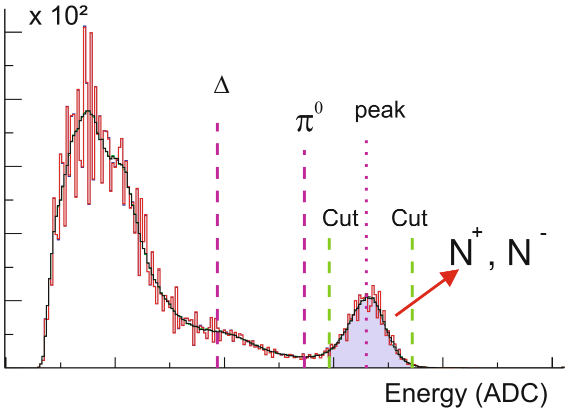

Fig. 7. Typical spectrum of scattered electrons in the A4 parity violation experiment showing a clear elastic peak. The π^0 production threshold and the $\Delta(1232)$ resonance position are indicated as well.

The A4 collaboration is studying parity violating electron-proton scattering $p(\boldsymbol{e}, e')p$ in order to measure the hidden strangeness content of the proton. Scattered electrons are detected in a 1022 channel PbF_2 calorimeter, which covers scattering angles $30^0 < \Theta_e < 40^0$ in the full azimuth. A typical spectrum is shown in Fig. 7. The result of the strange form factors at $Q^2 = 0.1(GeV/c)^2$ at a mean scattering angle of 35° is $G_E^s + 0.106 G_M^s = 0.071 \pm 0.036$ [2]. Meanwhile, the detector setup has been changed to backward angles, and measurements are in progress in order to separate G_E^s and G_M^s. It is planned to continue this program with a deuterium target, both with longitudinally and transversely polarized electrons.

The X1 collaboration is using the low-emittance MAMI beam for production and application of coherent radiation in the X-ray range. One example among many other applications is the X-ray phase contrast imaging [7] of low-absorption materials such as a leaf. With this technique images of high contrast can be obtained revealing details of the inner structure of the object, which would not be possible using the standard absorption method.

4 Status of MAMI C

The energy upgrade of MAMI to 1.5 GeV (MAMI C) by adding a harmonic double-sided microtron (HDSM), see Fig. 8, is well underway and the installation of all components is nearly finished. The Racetrack microtron concept could not be used for this stage, since the two end magnets would have a weight of about 2500 tons each, technically and financially impractical. The development of a double-sided microtron (DSM) with four inhomogeneous 90^0 magnets of about 250 tons each and two parallel accelerating sections circumvented this problem. The limitations of the available floor space together with the microtron coherence condition required the use of a frequency of 4.9 GHz, the first harmonic of the MAMI B frequency of 2.45 GHz. Since the accelerator structures as well as the klystrons are not commercially available at this frequency, a huge amount of in-house development and prototyping had to be faced. Phase stability considerations led to leave one of the two linear accelerators at 2.45 GHz. Fig. 9 gives a view of the individual vacuum tubes and steering magnets of the 43 tracks between magnets 3 and 4. A detailed recent description of the HDSM is contained in Ref. [8]. The first injection of the 855 MeV beam into the HDSM was achieved end of September, just two weeks ago. A first

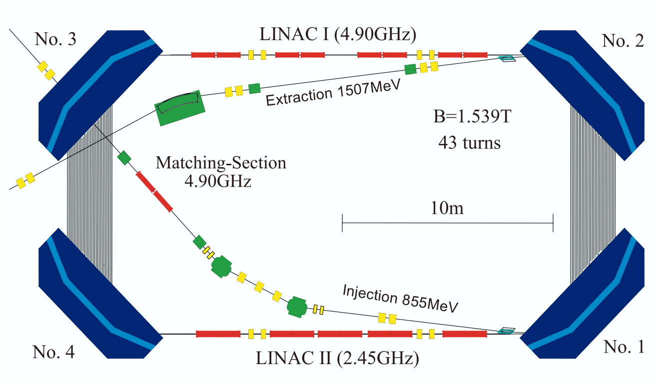

Fig. 8. Detailed scheme of the Harmonic Double-Sided Microtron (HDSM) for MAMI C.

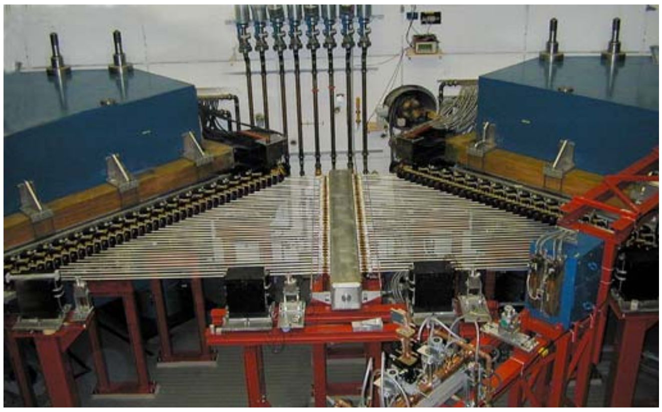

Fig. 9. View of the 43 recirculating tracks between magnets 3 and 4 of the HDSM.

accelerated diagnostic test beam is expected at the end of 2006, the full beam will be delivered into the experimental halls at the beginning of 2007.

5 Future plans and perspectives

The new facility MAMI C with an energy of 1.5 GeV will provide the opportunity to probe further into the structure of strongly interacting systems, i.e. hadrons and nuclei. In particular, the thresholds for kaon, η', ϱ and ω production will be exceeded, see Fig. 10. This will open up the possibility to study effective field theories and chiral dynamics in the open-strangeness sector, where little is known about their applicability. The 3-spectrometer setup of the A1 collaboration is being complemented by the KAOS spectrometer (Fig. 12) from GSI (Darmstadt) with a maximum momentum of 1.6 GeV/c, a solid angle of 20 msr, and a resolution of 10^{-4}. Its short length of 6 m provides a good survival probability for kaons. It is planned to study kaon electroproduction close to threshold and to investigate hypernuclear physics. For these studies, KAOS will ultimately be used as a double-arm forward spectrometer. The present status of the setup and a detailed overview of the planned experiments is given by P. Achenbach [9] at this conference. Further experiments include ^{3}He structure studies with a polarized ^{3}He gas target and high-precision measurements of the electromagnetic proton form factors.

A further significant access to the internal nucleon structure is given by the study of nucleon resonances. MAMI C will cover the complete second and third resonance regions, see lower part of Fig. 10. Of particular interest are small amplitudes, either of weak resonances or as small admixtures to dominating transitions, as it was successfully demonstrated in the case of the $\Delta(1232)$. The decisive problem is the fact that the higher resonances are broad and overlapping and have in addition to be separated from a non-resonant continuum background. In order to approach the goal of an ambiguity-free partial wave analysis, it is mandatory to make full use of polarization observables. Polarized electrons as well a linearly and circularly polarized photons are available at MAMI.

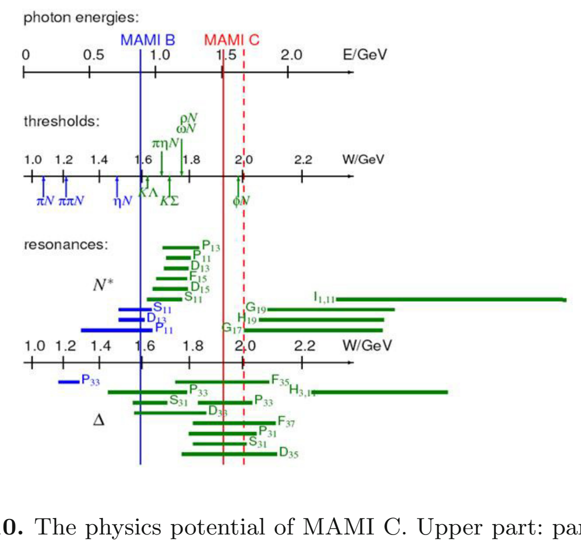

Fig. 10. The physics potential of MAMI C. Upper part: particle thresholds, lower part: N* and Δ resonances.

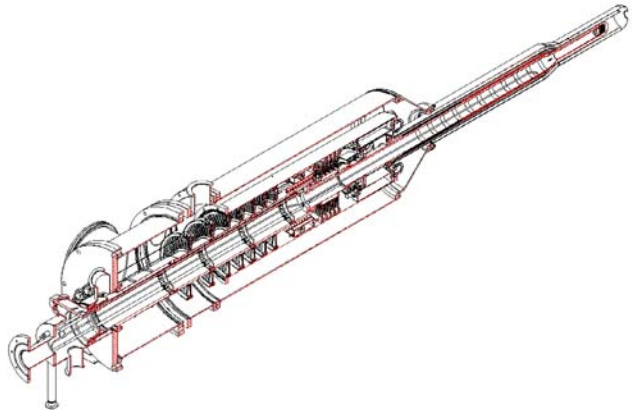

Fig. 11. The cryostat of the polarized frozen-spin target.

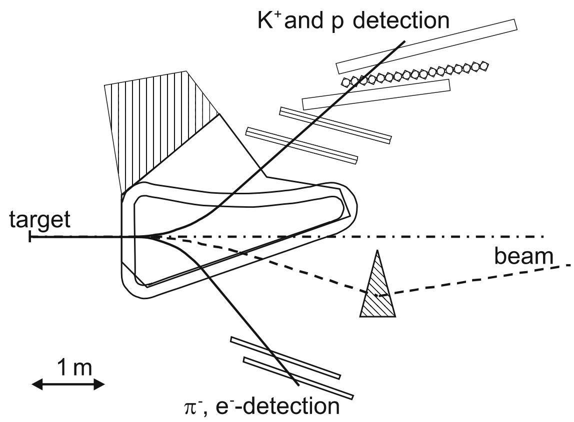

Fig. 12. The double arm kaon spectrometer (KAOS).

A polarized frozen-spin target for protons and deuterons (see Fig. 11), and a polarized ^{3}He gas target to be used with the real photon beam are in preparation. A recoil proton polarimeter will be installed in the Crystal Ball/TAPS setup. An incomplete list of experiments planned includes the helicity structure of the γp and γn interactions, the magnetic moment of the $S_{11}(1535)$ resonance, rare η and η' decays, in-medium modification of the ω mass, and kaon photoproduction.

MAMI is an ideal facility to study the non-perturbative structure of hadrons, in particular the distributions of charge, magnetization, and hidden strangeness inside the nucleon and light nuclei, the polarizabilities of nucleons and pions, the threshold production of pions and η mesons, and the excitation of low-mass nucleon resonances. With the upcoming energy upgrade MAMI C will enlarge this potential substantially, in particular to higher resonances and into the open-strangeness sector.

The operation of MAMI would not be possible without the strong and continued support of the Mainz University and the State of Rhineland-Palatinate. We are very grateful to the state and the federal ministries, who financed the construction of the accelerator and equipment via the university construction program (HBFG). The physics research program at MAMI is supported by the Deutsche Forschungsgemeinschaft (DFG) via the Sonderforschungsbereich SFB443, which is of great importance to our PhD students and postdocs. The access of the high number of external collaborators to MAMI is highly facilitated by the European Community Research Infrastructure Activity under the FP6 program (HadronPhysics, RII3-CT-2004-506078). Last not least MAMI gives excellent training opportunities to our students.

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