RECENT CHALLENGES FOR THE 1.5 GEV MAMI-C ACCELERATOR AT JGU MAINZ*

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Abstract

The MAMI-C accelerator is a 1.5 GeV microtron cascade for up to 100 μA polarised electrons operating CW at Mainz University [1]. Recent experiments required spin manipulations and beam energies not routinely supported by the accelerator. In particular, this required a spin orientation vertical to the accelerator plane and operation at beam energies which could not be achieved by the so far established methods. This presentation describes the challenges to provide and to characterise the unusual modes of operation.

VERTICAL BEAM POLARISATION

Starting in 2014 the first physics experiments with vertical spin polarisation were performed with MAMI at the A1 three spectrometer facility which was foreseen already when the very first polarised beam was accelerated at MAMI [2]. An overview over the MAMI accelerator is shown in Fig. 1.

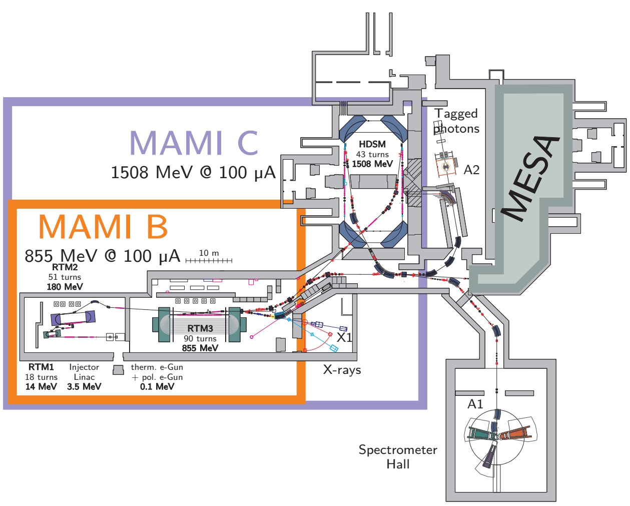

Figure 1: Floor plan of the MAMI accelerator.

Over the years, modifications of the injection system of MAMI were made which aimed at control of spin polarisation in the horizontal plane of the accelerator (dedicated polarised gun in the accelerator hall, Wien filter for horizontal spin alignments at 100 keV, Mott polarimeter at 3.5 MeV [3–5]). Most experiments ask for longitudinally polarised electrons because the spin correlated signals are enhanced by relativistic effects.

Due to Thomas precession in electromagnetic fields the spin precesses around the magnetic field with an angular frequency

$$\omega_S = (1 + a\gamma)\omega_C \tag{1}$$

where $\omega_C = eB/m\gamma$ (e, m=electron charge and rest mass, $\gamma = 1 + T/m$ with T=kinetic energy) is the cyclotron frequency and $a = (g-2)/2 \approx 1/862$ is the electron anomalous magnetic moment. That leads to individual settings of the horizontal Wien filter for each energy resp. microtron stage and experimental hall. Mott asymmetries can be measured reliably for Wien filter spin rotation angles of more than 30°.

Vertical spin orientation is in principle easier because this is the spin stable direction, i.e. there is no change of the spin direction during acceleration. In this case spin and magnetic fields are (anti-) parallel. Our existing polarimeters (Mott, Møller, experimental Compton [6, 7]) can measure components of the spin vector which are in the accelerator plane, but no polarimeter is installed so far to measure the vertical component. Therefore, the vertical spin component has to be inferred from measurements of the others.

Spin Manipulation

The 100 keV injection beam line and the 3.5 MeV injector linac are equipped with a few double solenoids (with reverse polarity of each solenoid) to focus the beam with $f^{-1} \propto \int B_z^2 dz$ without rotating the transverse phase space and the spin correspondingly. A horizontal component of the spin can be rotated along the longitudinal magnetic field into vertical direction with $\phi \propto \int B_z dz$. By choosing a suitable distribution of the fields in the two coils the focal length can be kept fixed while achieving the desired spin rotation as illustrated in Fig. 2.

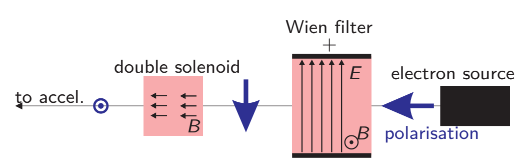

Figure 2: Schematic bird's eye view of the 100 keV beam line with important spin manipulation elements.

Setting and Verifying Vertical Spin Orientation [8]

The originally longitudinally polarised beam is rotated horizontally by 90° with the Wien filter. Using the next downstream double solenoid to rotate the horizontal component into vertical direction could easily be verified by the vanishing Mott asymmetry. This method however cannot completely exclude longitudinal components of the spin as Mott is not sensitive to longitudinal and vertical components.

The new Compton polarimeter at 3.5 MeV is available for experimental measurements extending the original Mott

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beam line. A dedicated Wien filter scan (see Fig. 3) shows a zero crossing of the longitudinal component very close to the 88.4°-setting being used during the experimental beam time.

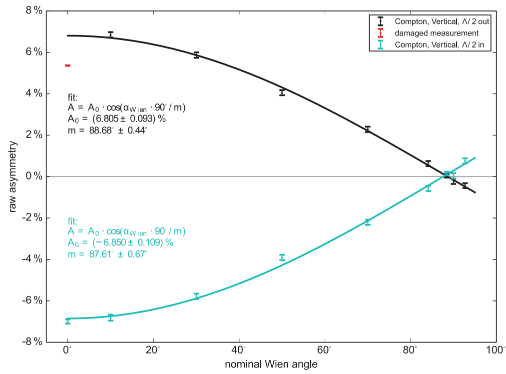

Figure 3: Compton asymmetries during the Wien filter scan with vertical setting of the solenoid.

Combined Measurements

A direct measurement of the vertical polarisation is neither available at low energies nor in the experimental hall. Therefore we combined the results of all measurements performed during optimisation for vertical spin and translated the results to the nominal energy of the experiment of 570 MeV into the spectrometer hall. Møller measurements performed at 855 MeV defined the absolute degree of polarisation. The Mott and Compton measurements at 3.5 MeV were rotated by the well known precession angle modulo 2π and gave constraints for horizontal components possibly remaining in the experimental hall. Møller measurements at 570 MeV constrained the longitudinal polarisation while measurements at 600 MeV could be used to constrain another horizontal direction after being rotated back to 570 MeV (see Fig. 4).

OPERATING MAMI AT 1402 MEV

The MAMI-C accelerator uses the Harmonic Double Sided Microtron (HDSM) to accelerate the 855 MeV electron beam of MAMI-B up to 1508 MeV (see Fig. 1). One great advantage of the MAMI accelerator cascade is the flexibility with respect to the extracted beam energy. That is simply achieved by installing an extraction magnet onto the corresponding return path and thus ending the acceleration process with reduced energies in steps of approximately 15 MeV. The energies routinely covered by that means extend from 180 MeV up to 1308 MeV. The gap of possible extraction energies between 1308 MeV and 1508 MeV exists due to limited space for the steerer magnets in the HDSM for turns 30 to 43 (see Fig. 5).

Tuning the Extracted Beam Energies

The minimum energy gain ΔE of a microtron is directly determined by the magnetic field B and the frequency $f =$

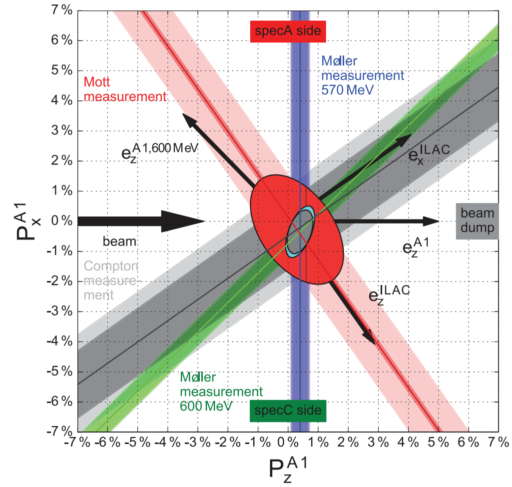

Figure 4: Reconstructed horizontal beam polarisation components for our optimised Wien filter and solenoid settings. The main component of the polarisation points in the $\vec{e}_y^{\,A1}$-direction for these settings. The result of a maximum likelihood fit when combining all available polarimeter data is shown as grey solid ellipse. Consideration of only the Mott and Compton result gives the red, combination of the two Møller measurements the cyan ellipse almost overlapping with the grey one.

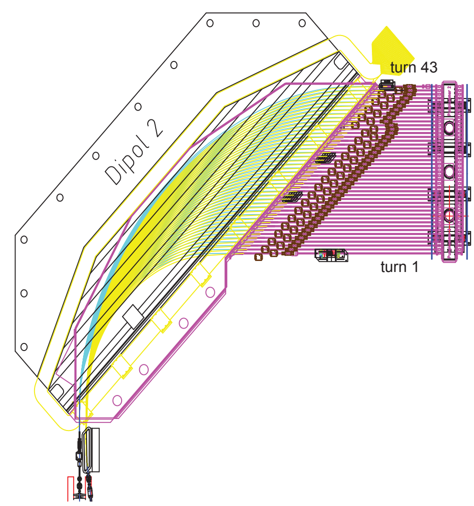

Figure 5: Schematic drawing of the extraction scheme of the HDSM. Variable energies are possible only up to turn 29 (i.e. 1308 MeV) due to the decreasing space left for the higher turns.

$1/\lambda$ of the RF system *(dynamic coherence condition)*:

$$\Delta E = \lambda \frac{2\pi}{e\beta c B} \qquad (2)$$

with e the electron charge, βc the speed of the electrons.

Tuning the energy of a microtron can be simply achieved by adjusting the magnetic field B. The energy gain ΔE has to be adopted to the newly chosen B by adjusting the accelerating field gradient. Tuning an accelerator like MAMI involves tuning of *all* microtron stages as the injection energy needs to be tuned, too.

To access energies lower than 180 MeV we tested machine settings with reduced magnetic and accelerating fields. However, that leads to major problems for our first microtron where the electrons are injected with 3.5 MeV kinetic energy in the common case. Reducing the injection energy results in different beam paths due to non-relativistic behaviour of the low energy beam (i.e. for $\gamma \leq 10$). During beam tests in 2013 we achieved a lowest energy of approximately 160 MeV using the cascade up to RTM2 [9].

Higher energies up to 1604 MeV can routinely be achieved by increasing the magnetic and accelerating fields of all microtrons which is a normal mode of operation for MAMI since early times [10]. That method also scales the corresponding extraction energies by a factor of 1604/1508 (from 191 MeV up to 1391 MeV). However, the maximum beam current is limited to a few micro ampere due to the fact that the RF power which is normally required to compensate for beam loading is used for higher accelerating field gradients.

Energy Scans for Experiments

For the precise measurement of the elastic electron-proton cross section to separate the electric and magnetic form factors in the Q^2 region from 0.1 $(\mathrm{GeV}/c)^2$ to 2 $(\mathrm{GeV}/c)^2$ at A1 we needed to provide among many other energies a beam energy of approximately 1400 MeV but at beam currents of 20 μA. Taking into account the limitations discussed above, the most promising and reliable approach for the demands of the experiment is to operate MAMI at design parameters. Therefore, we simply extracted the beam at 795 MeV of the 855 MeV of RTM3. With that injection energy the HDSM would accelerate the electrons up to 1402 MeV through all 43 recirculation turns.

Challenging Operation at 1402 MeV

With the beam being extracted at turn 82 instead of 90 turns for the RTM3 the time of flight from electron source to the HDSM is reduced by approximately 1 μs. Most diagnostic systems (luminescent screens, synchrotron monitors) do not rely on the precise timing. But to optimise the microtrons we use 10 ns short diagnostic pulses to separate the individual turns of each stage [11]. The data acquisition system is not prepared to expect the beam in the HDSM before the beam travels the whole cascade with all 90 turns of RTM3. Using a jitter-free delay while optimizing HDSM did the job and enabled the very sophisticated RF-monitor diagnostics of the HDSM with the same performance as in standard operation.

During the corresponding beam tests we demonstrated a beam current of 50 μA. The following experimental beam time only requested 20 μA and was successfully performed using beam energies of 720 MeV, 855 MeV, 1002 MeV, 1157 MeV, 1308 MeV, 1402 MeV and 1508 MeV within 3 weeks of data taking. The required time for setting up the different energies was less than 10 % of the whole beam time.

CONCLUSION

The MAMI accelerator is in operation for more than 25 years now and delivered more than 150.000 hours of beam time. Sustaining the high flexibility combined with reliable operation is our goal at least for the next decade.

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