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STATUS OF THE POLARIZED SOURCE AND BEAM PREPARATION SYSTEM AT MESA

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Abstract

The MESA Low-energy Beam Apparatus (MELBA) connects the DC photoemission source STEAM with the injector accelerator MAMBO. MELBA is capable of adjusting the longitudinal phase space for the requirements of the pre-acceleration by using a chopper and buncher while providing small transverse emittances. Measurements of the transverse phase space and longitudinal beam dimension taken at a test setup are presented. These results serve now for further improvements, e.g design changes in our corrector magnets. In addition, the revised MELBA will include two Wien filters and a solenoid for spin manipulation. A double scattering Mott polarimeter for spin diagnostics and a second source for the extraction of high bunch charges is foreseen using a branched off beam line. RF-synchronized laser diodes will be used with infrared wavelength as a driver for the spin-polarized photoemission. In this report we present the latest layout of MELBA and simulation results.

INTRODUCTION

The Mainz Energy-Recovering Superconducting Accelerator (MESA) is currently being built at the Institute for Nuclear Physics at the Johannes Gutenberg University in Mainz [1]. Its low-energy beam section MELBA includes a 100 keV DC photoemission electron source STEAM [2] which will provide the required 150 µA of spin-polarized electrons for the long-term P2 [3] experiment. Hence, the MELBA comprises of spin as well as phase space diagnostic and manipulation devices which will presented in the following. A branched off beam line extension is planned to allow an unpolarized high-current emission of > 1 mA for the second experiment MAGIX [4]. Figure 1 shows an overview of the current MESA layout.

OVERVIEW OF THE MELBA COMPONENTS

The latest MELBA beam line, which is about 9 m long, is illustrated in Fig. 2. A GaAs photocathode is activated in the preparation chamber and transferred to STEAM where it gets illuminated by a near-infrared laser light. STEAM then emits the electron bunches vertically into MELBA where an alpha magnet bends them by 270° into the accelerator plane. A differential pumping stage separates the region with extremely low pressure from the source ($<1\times10^{-11}$ m bar) and MELBA where the pressure is more than an order of magnitude larger. Two Wien filters and one solenoid will allow a 2π spin rotation in the accelerator plane. A double scattering Mott polarimeter (DSMP), which is located in a branched off beam line extension [5], suits the need of spin diagnostics at the beginning of the accelerator [6]. The first chopper cavity deflects the long bunches circularly over a movable slit cutting below $\phi \leq 180°$. A pair of solenoids focuses the deflected beam back to the reference orbit and the second chopper cavity cancels the superimposed transverse momenta. Afterwards the buncher accelerates the bunch tail and decelerates the head respectively resulting in a longitudinal focusing into the first acceleration section MAMBO (Milli-Ampere Booster) [7].

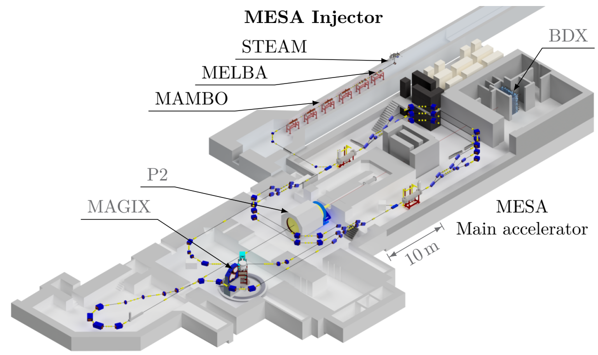

Figure 1: MESA operating parameters $f = 1.3$ GHz, $E_{EB} = 155$ MeV | $E_{ER} = 105$ MeV, $I_{EB} = 150$ µA | $I_{ER} = 1$ mA.

LOW-ENERGY BEAM SECTION

STEAM and the MELBA sub-components (except for the Wien filter and DSMP) had been built into a test setup [8, 9] from which we drew conclusions on how to update the MELBA with respect to emittance growth suppression and increased photocathode lifetimes.

Source

STEAM is a photoemission DC electron source designed for 200 kV with an accelerating field of 5 MV m^{-1}. It's operating voltage is 100 kV as the MELBA components are laid-out for $\beta = 0.548$. Due to its compact design STEAM is suitable to be built-up in the constrained tunnel where the MESA injector is planned (Fig. 1). A second vacuum chamber is attached to STEAM providing a swift insertion of new or reactivated photocathodes.

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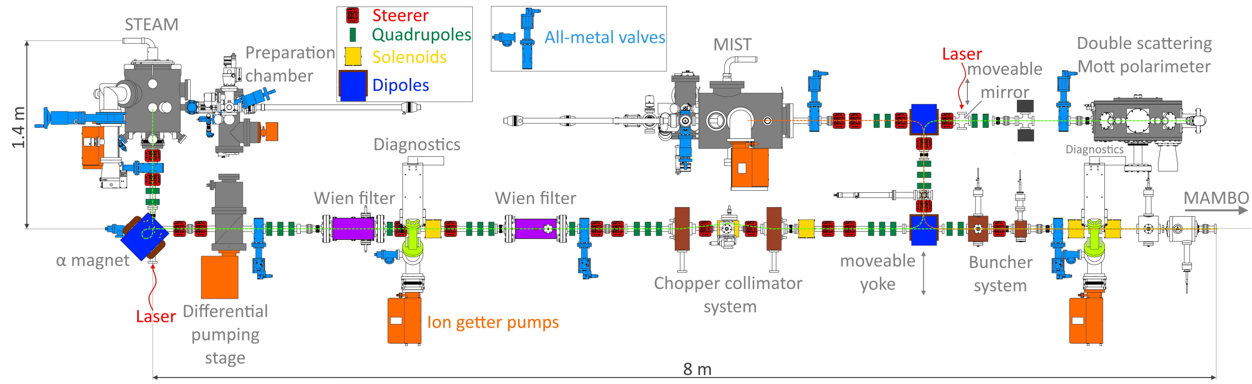

Figure 2: Scheme of MELBA, the low-energy part of the MESA injector.

Laser System

A CW laser synchronized to the MESA master oscillator will be used to illuminate the GaAs/GaAsP superlattice type photocathodes at 780 nm [10]. The initial quantum efficiency (*QE*) of 0.5 % corresponds to a photosensitivity of 3 mA W^{-1}. To achieve average electron currents up to 1 mA, a laser power of 5 W is required, which includes a buffer to compensate for the decay of the photocathode lifetime as well as transmission losses. The bunch charges will be kept constant for the two experiments, namely 0.12 pC for P2 and 0.77 pC for MAGIX. A reduction of the average current, i.a. for diagnostic or adjustment procedures, will be achieved by duty cycle variations of the semiconductor laser at the source.

Chopper and Buncher

The chopper consists of two deflecting cavities, a pair of solenoids and a collimator. The first chopper cavity circularly deflects the source beam over the collimator slit and thereby trims the longitudinal bunch width below 180°. The second cavity cancels the superimposed transverse momenta while the pair of solenoids compensates for the beam divergence leading the bunches back to the reference orbit [11].

Afterwards, the buncher cavities impress a linear velocity modulation onto the bunches. This results in a bunch head de- and bunch tail acceleration of which the focus is laid into the first section of MAMBO. Here the electrons are accelerated further so that the influence of space charge effects get suppressed.

Spin Manipulation and Diagnostic

The electrons emitted from the source are longitudinally spin-polarized which is also the required orientation for the P2 experiment. Passing through the MESA accelerator the spin precesses which has to be compensated for by the second Wien filter.

The Wien filters are replicas of the one used at the Mainzer Microtron (MAMI) [12]. Deduced from the Thomas-BMT equation, the spin rotation angle influenced by this device is proportional to its magnetic field $\Theta \propto B$. The required electric field is determined by the Lorentz force equilibrium $E/B = \beta c$. One Wien filter has an effective length of 0.32 m and requires a magnetic field strength of $B = 6.6$ mT ($E = 1.1$ MV m^{-1}) to rotate the spin by $\Theta = \pm\pi/2$. Both Wien filters and the solenoid permit a total spin rotation of 2π.

The degree of the polarization P can be determined with the DSMP. Using an unpolarized beam the effective analyzing power S_{eff} is determined by two scattering processes at thin gold targets. Subsequently, the polarized beam is scattered and the degree of polarization through the asymmetry measurement $A = PS_{\text{eff}}$. The DSMP will be inserted into a branched off beam line. Additionally, a 5 MeV Mott and a Hydro-Møller polarimeter [13] are also planned as spin diagnostic devices at higher energies within MESA.

EXPERIMENTAL RESULTS

STEAM was assembled in a test setup together with the chopper and buncher as well as a magnetic guiding and vacuum system. Two different 800 nm laser systems had been used, one with a small RMS laser spot size and a second one with up to 5 W for the high-current extraction of several milliamperes. Some of the photocathode lifetime and high-current extraction studies of bulk-GaAs as well as emittance measurements have been reported earlier [8, 9].

It was found, that the aim transverse emittance of < 1 mm mrad can be achieved, though higher order multipoles contribute significantly to emittance growth which was enhanced by a non-optimal magnetic shielding in the test setup. Especially if the steerer fields were strongly excited the emittance grew by a factor of 5. As about 20 orbit-correcting steerer magnets will be installed in the MESA injector this is why multipole-suppressing steerer magnets are under development for the buildup.

A Smith-Purcell radiation detector was installed at the position, where the MAMBO section will start in the actual injector. For bunch charges between 0.2 pC to 0.8 pC the measurement of the minimal longitudinal beam size calculated from the emitted Smith-Purcell radiation at this point yielded $\sigma_s \approx 45$ µm to 90 µm ($\sigma_\phi \approx 0.13°$ to 0.26°) [14].

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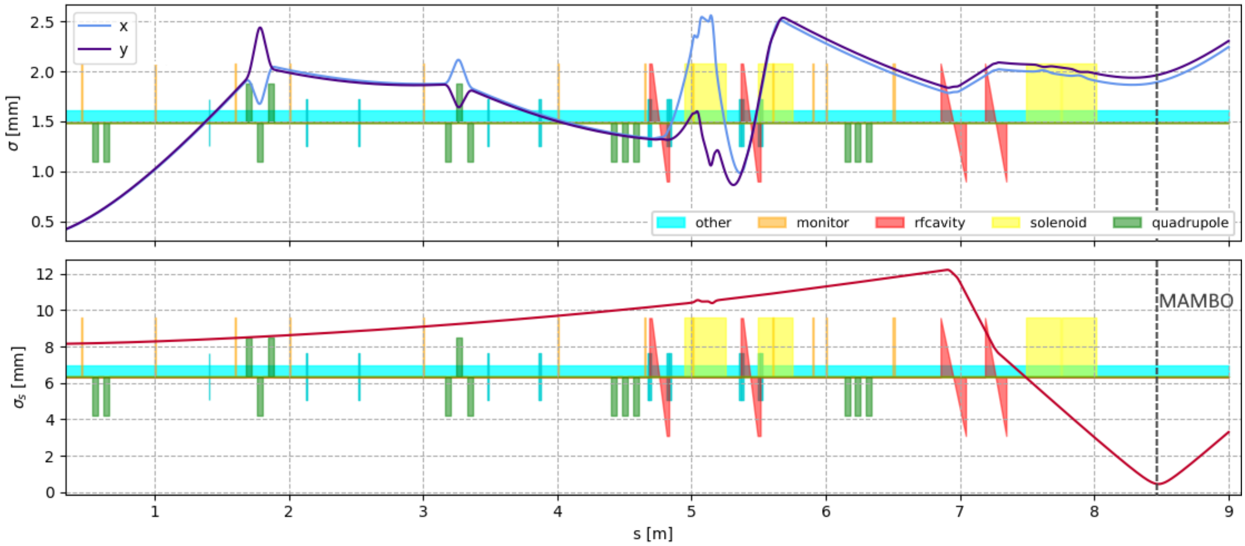

Figure 3: OPAL simulation of MELBA. Upper: Transverse RMS envelope. Lower: Longitudinal RMS beam size.

Long-run experiments revealed that charge lifetimes of 11 C for 10 µA and 3 C for 155 µA were extractable. The main reason for this turned out to be ion back bombardment initialized by the long laser pulse and electron bunch duration of several 100 µs resulting in 70% losses in the chopper system. This will be suppressed in the actual MELBA by the use of RF-synchronized laser pulses with durations in the order of 50 ps.

Lastly, the beam energy was increased from nominal 100 keV up to 150 keV. Up to 120 keV the emittance per energy dropped by 60% but above 120 keV the magnet currents had to be increased which led again to an emittance growth due to the increased influence of multipoles. Hence, MELBA will be operated at 100 keV as an increased beam energy would require the costly and time-consuming redesign and optimization of the chopper and buncher cavities.

SIMULATIONS

MELBA was simulated with the Object Oriented Parallel Accelerator Library [15] (OPAL). STEAM was simulated in Computer Simulation Technology [16] (CST). The emitted particle distribution was exported, weighted by the macro-charge and converted to a distribution readable by OPAL. The double solenoids as well as the chopper and buncher were also simulated in CST and the fieldmaps imported in OPAL, however the alpha magnet and the Wien filters have yet to be implemented. Table 1 lists the simulation parameters of the initial bunch distribution and the results the entry of MAMBO, i.e. after 8.5 m. The simulation results in Fig. 3 visualize the transverse RMS envelope in x and y direction as well as the bunch length σ_s. The focusing by the first and second quadrupole triplet is sufficient to focus the beam inside the chopper system and due to the short initial bunch length no losses occur in the collimator nor in the rest of the beam line. The total bunch charge of 1 pC remains after around 8.5 m with a normalized RMS emittance of 0.7 mm mrad at a bunch length of 0.5 mm which satisfies the requirements of MAMBO and the experiments.

Table 1: Simulation Parameters of the Initial and Final Bunch Distribution after 8.5 m at the Entrance of MAMBO

Parameter	**Initial**	**Final**
Bunch size σ_r in mm	0.5	2
Bunch length σ_s in mm | °	8 | 22	0.5 | 1.4
Bunch charge q_b in pC	1	
Norm. emit. $\varepsilon_{\mathrm{n,rms},\perp}$ in mm mrad	0.1	0.7
RMS energy spread ΔE in keV	0.04	2.2
Electron energy E_kin in keV	100 keV	

SUMMARY AND OUTLOOK

The photoemission source STEAM and important components of MELBA, the low-energy beam section of the MESA injector, were built up in a test setup. Weak points decreasing the photocathode lifetime, e. g. transmission losses due to long laser pulse durations, and the negative influence of higher order multipoles as source of emittance growths were identified. Those effects will be suppressed in the buildup of MESA injector by exciting with adequate laser pulse durations. Additionally, the usage of a concave shaped puck in STEAM will provide smaller beam sizes and an improved steerer design will reduce the negative influence of multipoles. For the unpolarized high bunch charge operation a second photoemission source is planned [17]. The measurements and simulations show that the quality requirements of the MESA experiments can be achieved with the 100 keV beam line.

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