Commissioning and first data analysis of the Mainz Radius Experiment.

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Abstract

The Mainz Radius Experiment (MREX) is an experimental campaign with the aim of determining fundamental properties of the equation of state (EOS) of nuclear matter. All of the thermodynamic properties of a system of nucleons, including energy, pressure, temperature, density, and the asymmetry between the number of neutrons and protons in nuclear-matter, are contained in the EOS. An important parameter, poorly-known at the state of current knowledge, is the slope of the symmetry energy at saturation density L, which quantifies the dependencies of the energy per nucleon associated with the changes in neutron-proton asymmetry. It is also an essential element for the determination of the radius of neutron star, whose description is still determined by the EOS, despite a difference of many order of magnitude with respect to the physical dimensions of the nuclei. The slope of the symmetry energy L is strongly correlated to a characteristic shown by heavy nuclei, the neutron-skin thickness, that is the difference between the spacial distribution radius R of neutrons and protons. Nowadays it is well-known, thanks to various nuclear physics experiments, that the neutrons of a nucleus tend to accumulate at a larger radius, forming a neutral thin layer around atomic nuclei. This peculiar characteristic is known in literature as neutron-skin thickness. The experimental measurement of this quantity is the main method to estimate the value of L, which is used as an input to many theoretical models of neutron stars. MREX is focused on the determination of the neutron skin thickness of ^{208}Pb from parity-violating experiments (PV) performed at the future MESA electron accelerator in Mainz, that is currently under construction. The parity-violating experiments, where longitudinal polarized electrons scatter from a fixed target at a single value of momentum transfer, consist in the determination of the cross section asymmetry $A_{pv} = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$ related to the different longitudinal polarization state of the beam. The parity-violating electron scattering is a valid probe to determine the neutron-skin thickness, because it is highly sensitive to the neutron distribution due to the larger coupling of the Z^0 boson to the weak charge Q_W of neutrons, which is approximately -0.99 per neutron, while that of the proton is 0.07. In this context, it is necessary to determine one of the possible background sources for the PV experiments, known as beam normal single spin asymmetry A_n, or transverse asymmetry. The asymmetry A_n, that concerns transversely polarized electrons, comes from the interference between two Feynman diagrams where one or two virtual photons are exchanged, giving a contribution of the order of $20\,ppm$. Because the values of A_n are typically higher that A_{pv}, the presence of a small transverse electron polarization component could produce an effect that is of the same order of magnitude of the A_{pv}. The work of this thesis focuses on the measurement of the transverse asymmetry A_n carried out at the Mainz microtron accelerator (MAMI) on a ^{12}C target. The ^{12}C target is particularly suited for studying and testing the electronics systems and detectors that will be employed in the next phase of the MREX experiment, the determination of A_n for ^{208}Pb. The measurement consists in the determination of A_n using two Cherenkov detectors made of fused-silica materials coupled to 3 and 8 photo-multiplier tubes. The two detectors have been tested in the laboratory, together with the new electronics for the data read-out, that consist in the NINO-asic board with which the impulse signals coming from the detectors are acquired. The beam parameters, as the transverse position of the beam, the scattering angles, and the current intensity and energy are determined with particular accuracy because their variation over time can result in effects that overlap with A_n. This required the development of a new analysis program, processing the raw data to extract the beam parameters relevant for the analysis, and separating the contributions of the false asymmetries from A_n. The work consisted in a first part dedicated to the calibration of the monitors, to measure the parameters of the beam. The second part was focused on the analysis of the data collected during the beam time, removing the outliers, identifying possible errors and isolating the contribution of false asymmetries. A_n has been measured for electron-carbon scattering at a two fixed angles ($\theta_B = -22.5°$, $\theta_A = 22.5°$) corresponding to a transfer momentum of $Q^2 = 0.04\,\mathrm{GeV}^2$. The measured values are: $A_B = -21 \pm 5\,(stat)\,ppm$ for

detector B and $23.1 \pm 1.7\,(stat)\,ppm$ for detector A. The different sign of the two measurements is in agreement with the opposite kinematic, and the two measurements are compatible within 1 σ, and in agreement with the previous measurements performed at MAMI. The results obtained confirm the capabilities of the electronic systems and components used during the experiments and are encouraging in anticipation of the next measurement of the transverse asymmetry for lead.