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# High accuracy position response calibration method for a micro-channel plate ion detector

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ABSTRACT

We have developed a position response calibration method for a micro-channel plate (MCP) detector with a delay-line anode position readout scheme. Using an in situ calibration mask, an accuracy of 8 μm and a resolution of 85 μm (FWHM) have been achieved for MeV-scale $\alpha$ particles and ions with energies of ~10 keV. At this level of accuracy, the difference between the MCP position responses to high-energy $\alpha$ particles and low-energy ions is significant. The improved performance of the MCP detector can find applications in many fields of AMO and nuclear physics. In our case, it helps reducing systematic uncertainties in a high-precision nuclear $\beta$-decay experiment.

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## 1. Introduction

For more than two decades micro-channel plates (MCPs) have been widely used for ion and electron detection in experiments dedicated to the study of ion, atom and molecule collisions and photoionizations using the so-called "cold target recoil ion momentum spectroscopy" (COLTRIMS) technique [1]. More recently, such detectors found new applications in nuclear physics with the precise measurement of atomic masses of short lived nuclides [2] and high-precision nuclear $\beta$-decay experiments [3–6]. Many of these experiments demand high accuracy and resolution for both the timing and position responses of the MCP. For example, in the measurement of the $\beta$–$\nu$ angular correlation in the $^6$He decay at University of Washington [7,8], the MCP detector is used to detect the impact positions of the recoil $^6$Li ions and to provide the stop signal for the ion time-of-flight (TOF) measurement which is triggered by the detection of the $\beta$ particles from $^6$He decay. For each event, the ion position and its TOF are needed for reconstructing the initial momentum of the recoil ion and with it the momentum of the outgoing anti-neutrino. The fiducial cut on the MCP image affects the TOF spectral shape and thus the extracted value of the $\beta$–$\nu$ angular correlation coefficient $a_{\beta\nu}$. It is thus very crucial to calibrate the MCP position response to a high accuracy for such experiments.

To make an MCP detector position-sensitive, a resistive anode [9], a wedge-and-strip anode (WSA) [10], or a pair of delay-lines [11] perpendicular to each other are placed behind the MCP to collect the cloud of electrons. A phosphor screen coupled to a CCD camera can also be used, but at the cost of losing high-resolution timing information correlated with position. For the resistive-anode scheme, the electron-collecting position is determined by the ratios of the charge collected at four corners of the resistive anode, while for a WSA anode it is deduced from the ratio of three charges collected on the WSA pattern. For the delay-line scheme, $X$ and $Y$ coordinates are encoded in the time differences between the signals read from the two ends of two perpendicular delay-lines. A resolution of ≈100 μm has been achieved using these anode configurations, and there are also many studies on improving MCP position resolutions for different types of impacting particles [12], counting rate [13] and configurations of MCPs like the number of layers [14]. However, distortions around 200 μm are inevitable for all position readout schemes [13,15,16]. Particularly, distortions are large near the edge of the MCP detector due to fringe electric fields. Therefore a position calibration procedure is needed to achieve a high accuracy. Conventionally, the position response of an MCP detector is calibrated using a mask with holes or other patterns at well-machined positions [16–18]. Then the MCP is

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illuminated with $\alpha$ particles [18], low-energy ions [16], low-energy electrons [15] or ultraviolet photons [13] such that the mask pattern is imaged onto the MCP. Usually, a global correction algorithm for the whole MCP is obtained by comparing the imaged hole positions reconstructed by the MCP detector to the actual hole positions on the mask. For example, an accuracy of 240 μm was achieved for the delay-line position readout scheme [16]. If a local correction algorithm is implemented so that the position correction of an event is based on the positions of the holes near this event, the position accuracy can be improved to 120 μm [18].

The position accuracies of the conventional calibration schemes described above are limited to about 100 μm. Moreover, there are two drawbacks of these methods. Firstly, after the calibration is done, the calibration mask needs to be removed, and this involves venting the vacuum chamber and disassembling part of the detector system for the experiment. It is also hard to control the stability of the calibration throughout the experiment when the mask is no longer mounted on the MCP. Secondly, the mask is usually positioned at some distance from the MCP surface, which requires a good understanding of the particle trajectories. This implies a very precise knowledge of the $\alpha$-source position or of the ion flight path which is usually driven by an electric field.

To overcome these difficulties, we developed a calibration scheme using a 90% open calibration mask with precisely shaped orthogonal grids placed directly on top of the MCP surface. In this way, the open area of the mask is large enough so that there is no need to remove the mask after the calibration. The shadow created by the mask is present on the MCP image during the experiment, and thus the position calibration is built into the data. Since there is no gap between the mask and the MCP surface, the requirement of knowing the trajectories of the incoming particles is less strict. In order to achieve a higher position accuracy, we developed an algorithm to determine the positions of the grid lines on the MCP image and then correct the detector position response. In this paper, we will describe the MCP detector system used to develop and test this position calibration method. The position calibration method and its performance will be described in detail. We will also discuss the performance of the MCP detector position response in an experiment using laser-trapped $^6$He atoms [19].

## 2. Apparatus and detector operations

The experimental setup used to test and calibrate the MCP detector is shown in Fig. 1, and this setup is also used in the $^6$He $\beta$–$\nu$ angular correlation measurement [8]. In the $\beta$–$\nu$ angular correlation measurement $^6$He atoms are laser-trapped at the center of the vacuum chamber shown in Fig. 1. A $\beta$-telescope which consists of a multi-wire proportional chamber and a scintillator detector is placed above the trap, and an MCP detector is placed below the trap for detecting recoil ions. Electrodes are installed in between the $\beta$-telescope and the MCP detector to create an electric field of $\approx 1.3$ kV/cm and accelerate the recoil ions emitted from the trap towards the MCP detector to $\approx 13$ keV. Therefore the ion-collecting solid angle becomes larger and the ions have enough energy to trigger the MCP detector with high and uniform efficiency [16]. In this system, calibration sources can be inserted to the trap position via a transportation rod. The MCP tests and calibrations use some or all of this setup in those tasks described in the following sections.

The MCP detector system is based on the DLD80 system [11] developed by RoentDek with two MCPs mounted in a chevron configuration. The diameter of each micro-channel is 25 μm, and the distance between adjacent channels is 35 μm. The micro-channels are inclined at 8° relative to the normal direction of the MCP surface. We have modified the system by mounting the MCP

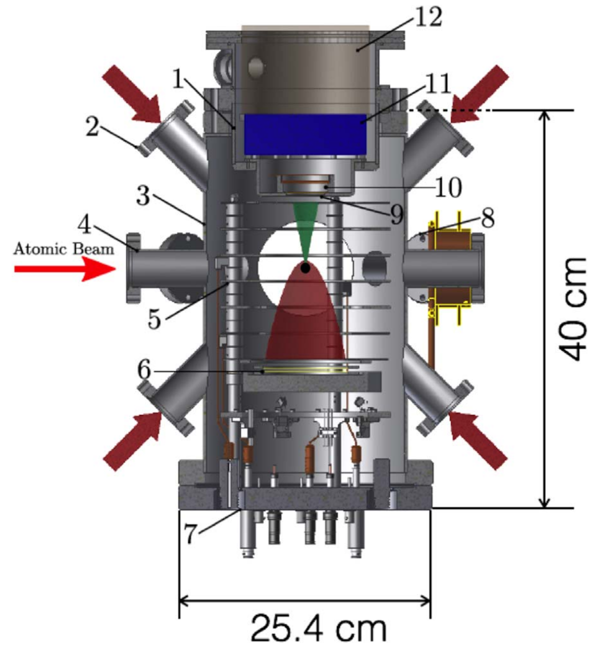


**Fig. 1.** Cross-section view of the detector system mounted on the $^6$He-trap chamber: (1) re-entrant $\beta$-telescope housing, (2) trapping laser ports, (3) main chamber, (4) $^6$He transfer port, (5) electrode assembly, (6) micro-channel plate (MCP) recoil-ion detector, (7) 10 in. custom feedthrough flange for HV and MCP connections, (8) trap monitoring ports, (9) 127 μm Be foil, (10) multi-wire proportional chamber (MWPC), (11) plastic scintillator, (12) lightguide to photo-multiplier tube. The black dot at the chamber center is the position of the $^6$He trap used in the $\beta$–$\nu$ correlation experiment and the test with trappe $^6$He atoms described in Section 4. The trap is 91 mm above the MCP. The green cone represents the $\beta$-detection solid angle, and the magenta parabola is the envelope of all possible $^6$Li ion trajectories. This figure was originally produced in Ref. [20]. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

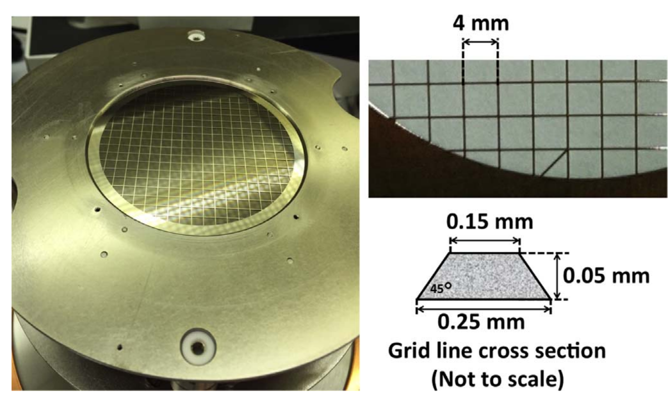


**Fig. 2.** Photo of the micro-channel plate with the calibration mask placed on top of it. The zoomed-in picture of the calibration mask and the grid line cross section are shown on the right. The diagonal line in the bottom square is to mark the orientation of the mask.

stack to the bottom electrode (the MCP holder) of the recoil-ion spectrometer. The 50 μm thick nickel calibration mask (Fig. 2) is fixed to the MCP holder and kept flat with four screws, and the MCP stack is clamped to the bottom of the calibration mask by a ceramic ring as shown in Fig. 3. The MCP holder, the calibration mask, and the top surface of the MCP stack are in electrical contact with each other. The shim electrode and the delay-line anodes are adjusted so that the MCP stack is at the position recommended for the DLD80 system by RoentDek. The calibration mask is produced through *electroforming* [21], and nickel is chosen for sake of its stiffness. The grid lines of the calibration mask are separated by 4 mm, and the width of each grid line is 250 μm. The accuracy of