Detection of recoil ion in the beta decay of laser oriented trapped radioactive isotopes for the MORA Project

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Abstract. The Matter's Origin from RAdioActivity (MORA) project focuses on ion manipulation in traps and laser orientation methods for the searches of New Physics (NP) in nuclear beta decay by precisely measuring the D correlation parameter. We predominantly have focussed here on the detection configuration of MORA and alongside talked in detail about the Recoil Ion DEtection system (RIDE) and its characterization focusing mainly on the methods applied to achieve high order position correction.

1. MORA Detection setup

The MORA experiment[1] is searching for evidence of CP-violation in the nuclear beta decay of trapped and oriented $^{23}Mg^{+}$ and $^{39}Ca^{+}$ions. The employed detection setup uses an emiT[2] experiment-like configuration which alternates every 45 degrees, there is a dedicated detection system for beta particles and recoil ions emitted during the decay of the isotope of interest. The CP-violating D correlation parameter will thus be measured by an octagonal arrangement of recoil ion and positron detectors placed at 10 cm from the trap center, see Fig 1, by taking into account the asymmetry in the number of recoil-ion and positron coincidences recorded at average θ_{er} angles of +45°, +135° on one side and -45°, -135° on the other side, the sign of θ is being defined clockwise with respect to the spin direction. With the help of annular silicon detectors, which are placed upstream and downstream of the axis of the MORA trap, we measure the degree of polarization, which can be inferred from the beta asymmetry[3]. The arrangement of detectors measuring the D correlation is situated in the azimuthal plane of the trap, which consists of 4 assemblies of 4 dedicated Phoswich detection systems designed for the detection of beta particles and 4 assemblies of MCP (Microchannel plates) based detectors for the purpose of recoil ion detection. MCPs present attractive performances for low energy ion detection (few keV's) with efficiencies attaining 50%. They can be adapted for a range of localization anodes. For the purpose of the measurement of the D correlation to the 10% level, a position resolution

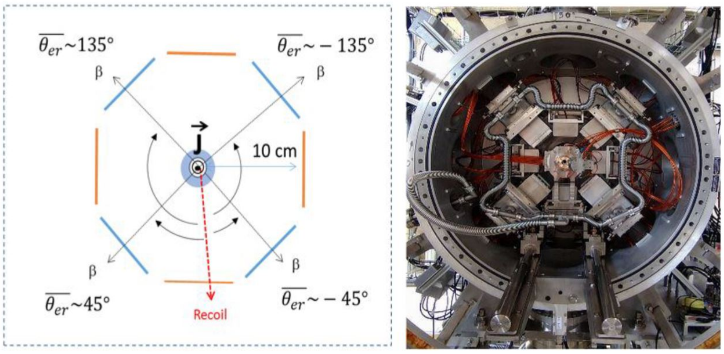

Figure 1. Magnified view of the D correlation detection setup, showing the different types of β-recoil coincidences, Current installation of MORA detection chamber at IGISOL accelerator facility of Jyväskylä in Finland

of the order of a few mm is more than sufficient. We describe here the assembly of MCPs and simple localization anode, then focus on the calibration in position.

2. RIDE Detection system

The RIDE detection system is equipped with MCP plates provided by Photonis[4] in a chevron configuration (8° in between microchannels and the incidence axis of particles) along with 90 % transmission grid on the front, a homemade Position sensitive anode at the back developed at LPC Caen and a reflective anode at the very end of the assembly. The total active surface of the wafer is of dimension (48:48)mm, where each microchannel has a diameter of 25μm, with a 35μm distance between adjacent channels. The employed position-sensitive anode deposited on a flex/PCB eventually collects the cloud of electrons generated as soon as an ion hits the MCP surface: the total charge gets spread on the surface of the resistive anode, which illuminates both horizontal strips and vertical pads in the position-sensitive flex at the same time, producing four signals; namely, Left, Right, Top, and Bottom which helps us to construct the detector image and to get an estimator of the x and y position. To construct the position of ions incident on the detector, we commenced the characterization process of the ride detection system by utilizing first an in situ stainless steel calibration mask of 0.15mm thickness having a uniform distribution of holes of 1mm in diameter at a 5mm pitch along with a cross shape opening of dimension (10:10)mm of 1mm thickness, corresponding to the center of the MCP detector. To obtain a piece of precise information about the position resolution of the events on the detector in space concerning the trapped ion cloud, the mask also exhibits L-shaped openings of the same 1mm thickness having the dimension of (5:5)mm engraved on each corner. The data is consisting of 5 short (<10 ns) signals, amplified by FTA 820 Ortec amplifiers, one for the MCP, and 4 for the four charges collected by the anode. It is recorded and digitized thanks to the FASTER data acquisition system, using the QDCs of the CARAS cards[4]. The data is retrieved in a .fast format binary file from the acquisition system and then converted into a root file to have the convenient tool to display and analyze it. We proceed first by obtaining the raw image of the detector by using four localization charges where $\tilde{x} = (Q_{right} - Q_{left})/(Q_{right} + Q_{left})$ and $\tilde{y} = (Q_{top} - Q_{bottom})/(Q_{top} + Q_{bottom})$. These estimators range from -1 to +1. The next step from here requires a translational displacement of the raw image at the origin, corresponding to the center of the physical mask. This step is performed by projecting the raw image on the x and y plane and multiplying the x and y estimators by obtaining scaling coefficients, which are

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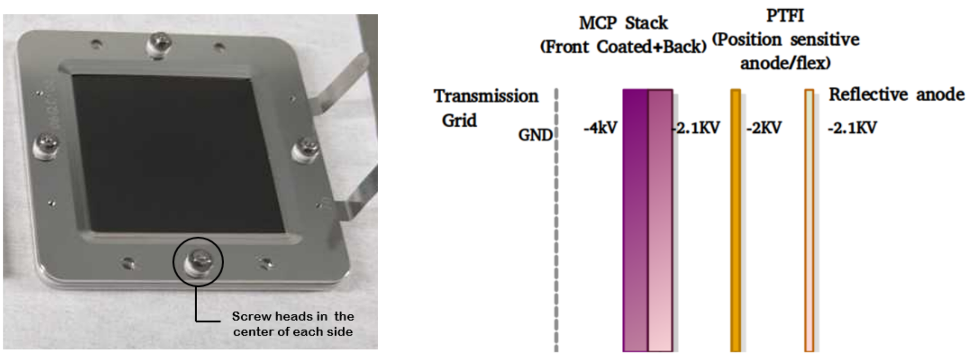

Figure 2. MCP backplane showing four visible screws maintaining the stack together, Schematic to illustrate the applied potentials on MCP front and back plates, the position-sensitive anode, and the reflective anodes

chosen such that the middle cross region is centered at the origin of the coordinate system. Using

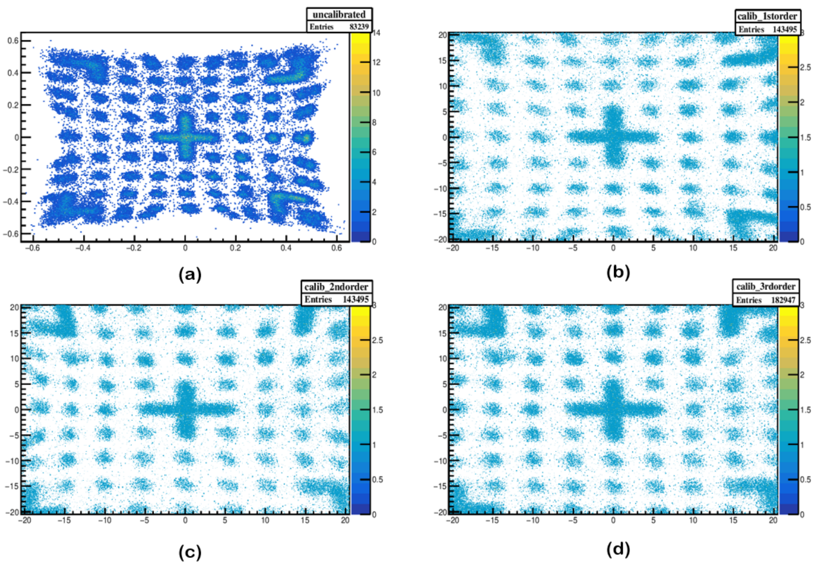

Figure 3. (a) Detector raw image constructed using four localization charges (b) Alignment in the center and first-order correction with respect to positions in the calibration mask (c) Reconstructed image after applying second-order correction polynomial (d) Final results with a third order polynomial correction function

the peak finding algorithm from the root libraries, it is possible to establish the relationship of the estimated x and y position for each hole opening to their actual physical position on the calibration mask within an acceptable range. We first use the first-order polynomial function to make the holes in the reconstructed image approximately corresponding to their exact position on the mask in mm. Using the TSpectrum class in the root analysis, we find the position of peaks that corresponds to the central cross and the small holes and inject the initial values of peak parameters to make a global fit. We then perform higher-order corrections to correct the visible distortion and reconstruct the obtained detector image. An example of a correction function using a third-order polynomial is illustrated in eq 1 and eq 2 for the x and y directions, respectively. where X_c and Y_c are the corrected positions obtained after applying the second-order correction function.

$$X_d = p_0 + p_1X_c + p_2Y_c + p_3X_c^2 + p_4Y_c^2 + p_5X_cY_c + p_6X_c^3 + p_7Y_c^3 + p_8X_cY_c^2 + p_9X_c^2Y_c \quad (1)$$

$$Y_d = q_0 + q_1X_c + q_2Y_c + q_3X_c^2 + q_4Y_c^2 + q_5X_cY_c + q_6X_c^3 + q_7Y_c^3 + q_8X_cY_c^2 + q_9Y_cX_c^2 \quad (2)$$

Now we will present an argument as to why to stop ourselves from going much further in the correction order. Once the electrons leave the MCP back plate, they experience an attractive force coming from the position-sensitive anode, biased with ∼100V less negative potential. Ideally, we assume that the electric field in between MCP plates and the anode has only one component which is perpendicular to the plates $\vec{E} = \vec{E}_\perp = (0, 0, E_z)$. Thus the trajectories of the electrons will follow a straight line perpendicular to the biased plates. However, some secondary sources can create a small electric field with some parallel components $\vec{E}_\parallel = (E_x, E_y, 0)$. In that situation the trajectories of the electrons will deviate slightly from the usual trajectory since there will be an extra force acting on them $\vec{F}_\parallel = (F_x, F_y, 0)$.

In our case, we have identified the major source of field distortion. It is related to the head of four screws maintaining the MCP stack together, visible on the back plate of the MCP in Fig 2. The potential of these 4 screws corresponds to the front voltage of the MCPs ~ -4kV, while the surface of the back MCP is ~ -2kV. The four screws will create an octupolar potential component parallel to the plates, proportional to $x^4 - 2x^2 \times y^2 + y^4$. As the screws are embedded within the frame of the MCP, the main component of the field remains perpendicular to the plates. We can safely assume that the time Δt for the electrons to reach the anode is about constant, regardless of the position. In this condition, the deviation of electrons on the anode with respect to their originating position will be proportional to the electric field i.e.,

$$\begin{aligned} \Delta_x &\sim \frac{\Delta t^2}{(2me)} Fx \propto 3x^3 - 4x \times y^2 \\ \Delta_y &\sim \frac{\Delta t^2}{(2me)} Fy \propto 3y^3 - 4y \times x^2 \end{aligned} \quad (3)$$

which are 3^{rd} order polynomials.

3. Conclusion

With the polynomial reconstruction's help, we corrected the raw image of the detector using the four localization charges in simple x and y position estimators. We have utilized correction polynomials up to the third order and justified that this correction was suitable to get a good agreement with the physical position of the holes in the calibration mask with the reconstructed position of points in the acquired data. After the reconstruction procedure, we could determine a position resolution of 0.8±0.4 mm in x and 0.9±0.4 mm in y, with an achieved position accuracy of better than 80μm in x and y for the holes fully reconstructed after applying the third-order correction.

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