Development of MCP based detection system for low energy β decay experiment

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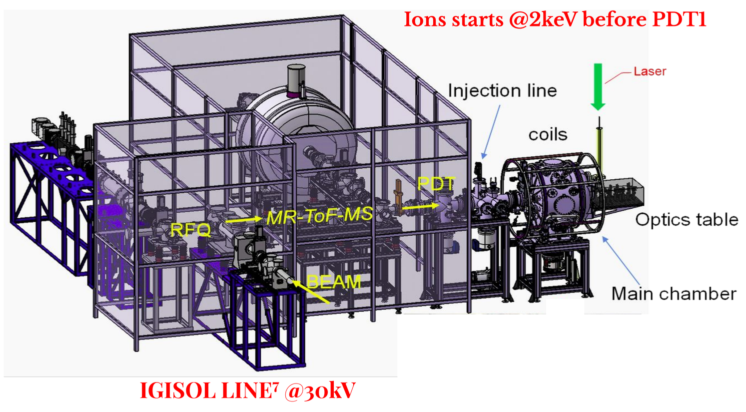
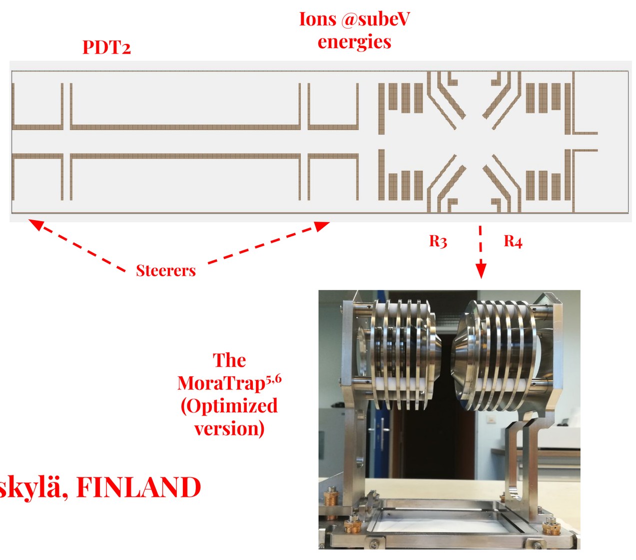
Physics Motivation

- In the framework of MORA[1,2] project, the searches for new sources of CP violation[3] has been carried out by measuring the D correlation[4] parameter in nuclear beta decay of ^{23}Mg
- Novel approach of combining the ion trapping , laser polarization and bunching techniques
- Monitoring of polarization of trapped ions using Annular silicon detectors
- The D measurement setup is composed of β (phoswich) and recoil-ion (MCP) detectors to observe the β-recoil coincidences
- Goal is to reach the sensitivity down to 10^{-5} in the measurement of D parameter
- Commissioning of MORA setup and the first proof of Polarization experiment from the year 2022-23





Ion Beam Manipulation @ IGISOL facility of Jyväskylä, FINLAND

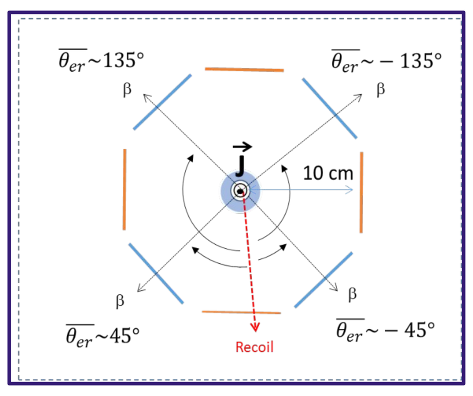
Beta decay rate equation

$$\omega(\langle J\rangle|E_e,\Omega_e,\Omega_\nu)\,dE_e d\Omega_e d\Omega_\nu = \frac{F(\pm Z,E_e)}{(2\pi)^5} p_e E_e (E_0-E_e)^2 dE_e d\Omega_e d\Omega_\nu$$

$$\times\frac{1}{2}\xi\left\{1+a\frac{\mathbf{p_e}\cdot\mathbf{p_\nu}}{E_eE_\nu}+b\frac{m}{E_e}+\frac{\langle \mathbf{J}\rangle}{J}\left[A\frac{\mathbf{p_e}}{E_e}+B\frac{\mathbf{p_\nu}}{E_\nu}+D\frac{\mathbf{p_e}\times\mathbf{p_\nu}}{E_eE_\nu}\right]\right\}$$

P even, T odd

via CPT theorem sensitive to CP violation

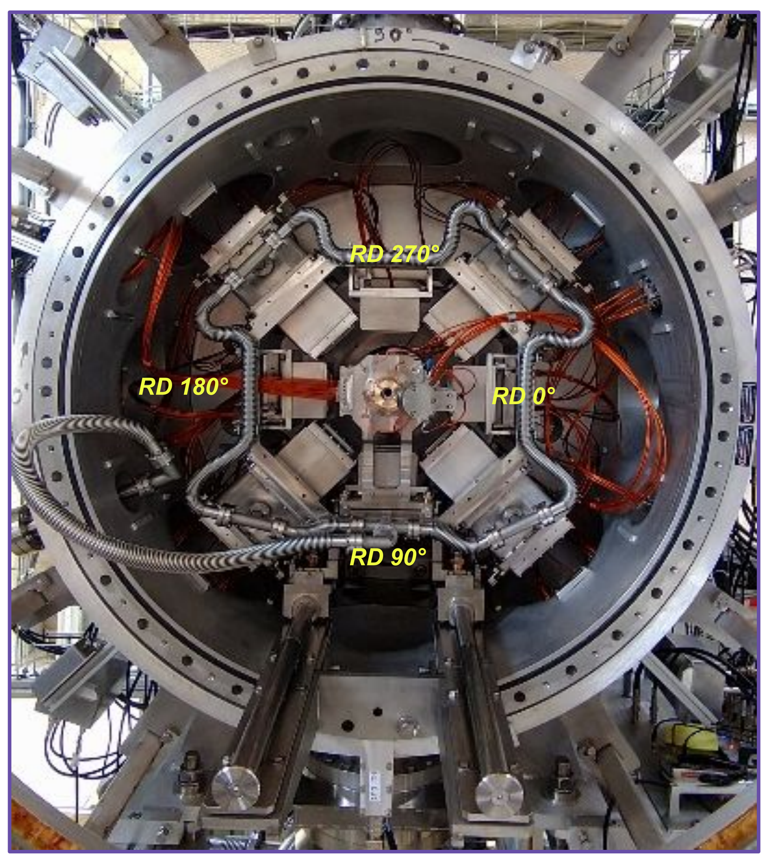


Different types of β-recoil coincidences which will be recorded by the detection setup. The asymmetry in the number of coincidences recorded at average θer angles being defined clockwise with respect to the spin direction gives D value

$$\frac{N^{+45°}_{coinc}+N^{+135°}_{coinc}-N^{-45°}_{coinc}-N^{-135°}_{coinc}}{N^{+45°}_{coinc}+N^{+135°}_{coinc}+N^{-45°}_{coinc}+N^{-135°}_{coinc}} = \delta\cdot D\cdot P$$

Sensitivity factor — D correlation parameter — Polarization degree

The D measurement setup

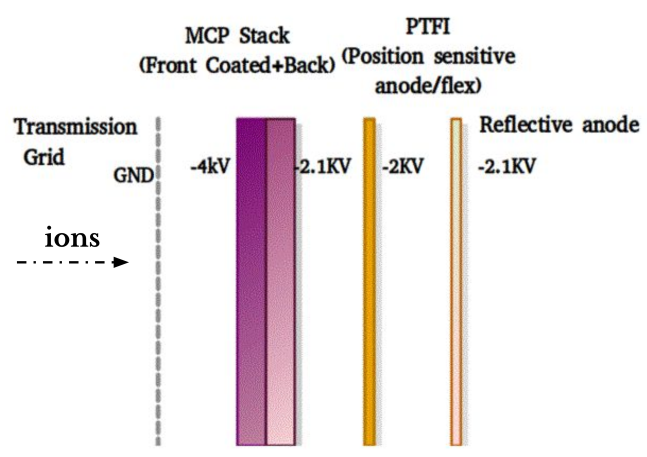


4 assemblies of RIDE detectors installed on the azimuthal plane of the MORATrap in the chamber during the first commissioning of the setup in Jyväskylä, FINLAND

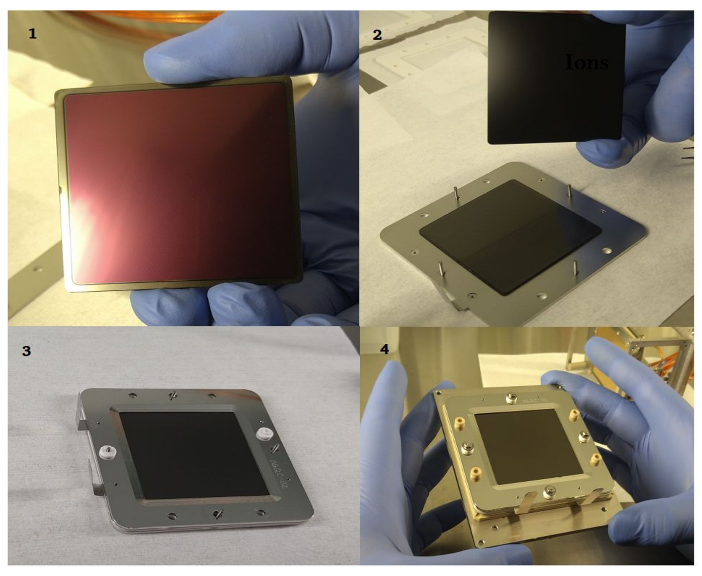
Characterization of RIDE[8] (Recoil Ion DEtector)

RIDE working principle

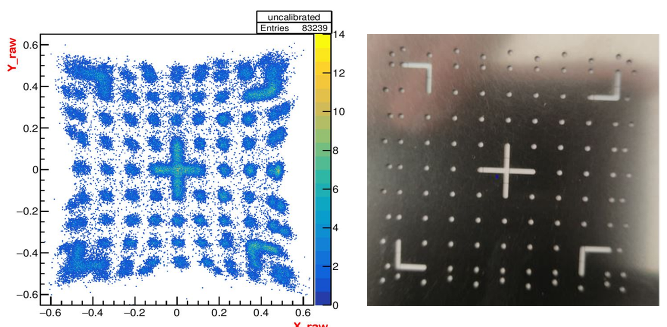
- MCP signal is amplified (about 10^6 times, depending on the polarization voltage) with particle hitting the surface
- The total charge Q_{total} is spread on the surface of the PTFI (resistive anode), illuminating its horizontal stripes and vertical pads, producing four signals (Q_{left}, Q_{right}, Q_{top}, Q_{bottom})
- The value of these four charges depends on the total charge and on the position of the incident particle



3 Polarization Voltages: front MCP, back MCP=reflection electrode, Position sensitive anode



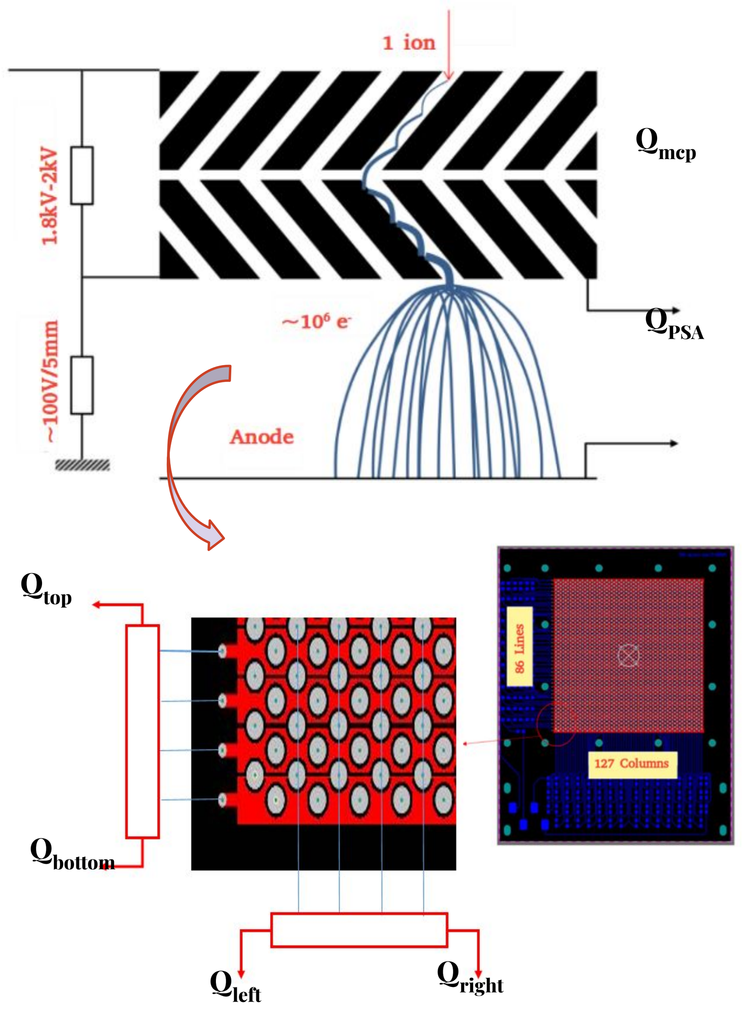
(1) MgO layer(front plate) (2) Back plate (3) base insulator surface, metallic conducting ring in b/w the plates (4) The frame holding the stack,metallic screws on each side



$$\tilde{x} = \frac{Q_{right}-Q_{left}}{Q_{right}+Q_{left}}$$

$$\tilde{y} = \frac{Q_{top}-Q_{bottom}}{Q_{top}+Q_{bottom}}$$

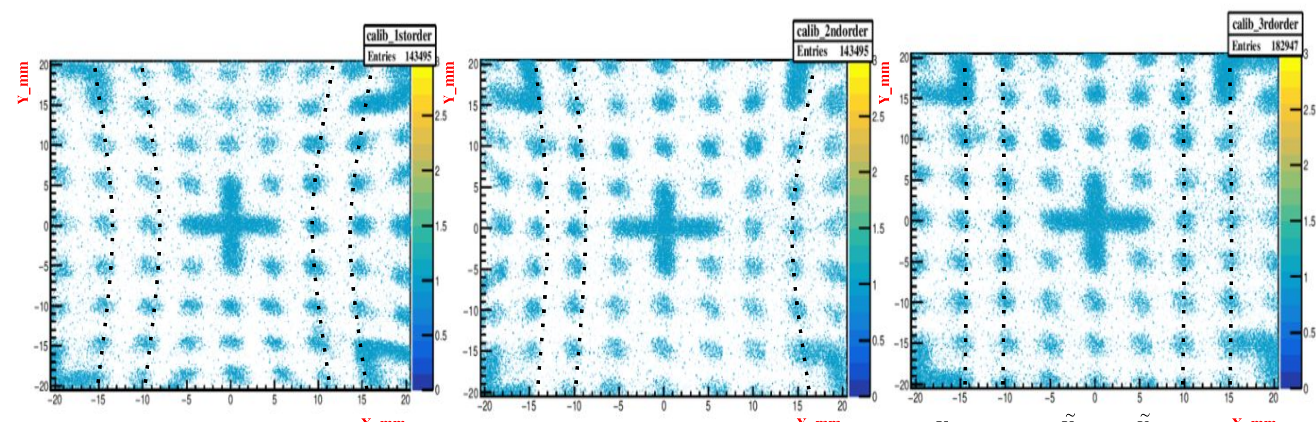
Stainless steel calibration mask of : Thickness ~ 1.5mm consists of : Small holes ~ 1mm(width), 5mm pitch, a centre cross ~ (10*10)mm, 1mm(width), and 4 L-shaped openings~ (5*5)mm, 1mm (width)



Electron avalanche principle in Micro-channel plates followed by their spatial distribution on the anode; Charge distribution from Position sensitive anode in four directions used to determine the MCP position readout.

Detector image reconstruction and position calibration

- The image construction formula is modified using the scaling factors for the basic stretching and shifting before applying the position calibration.
- Correction polynomials up to the third order are used in image reconstruction order to get a good agreement with the physical position of the holes and in the corrected real data.



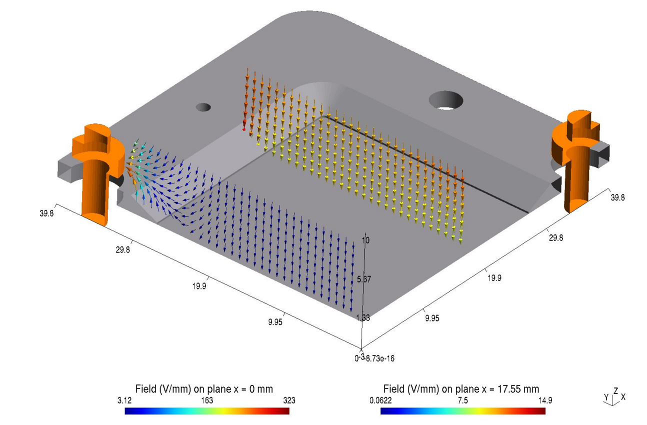
$$\tilde{x} = \frac{a.Q_{right}-b.Q_{left}}{a.Q_{right}+b.Q_{left}},\quad \tilde{X}=a.\tilde{x}+b,\quad \tilde{Y}=c.\tilde{y}+d$$

$$X_c = p_0+p_1\tilde{X}+p_2\tilde{Y}+p_3\tilde{X}^2+p_4\tilde{Y}^2+p_5\tilde{X}\tilde{Y}$$

$$Y_c = q_0+q_1\tilde{X}+q_2\tilde{Y}+q_3\tilde{X}^2+q_4\tilde{Y}^2+q_5\tilde{X}\tilde{Y}$$

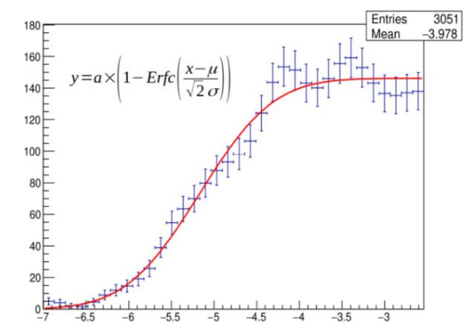
$$X_d = p_0+p_1\tilde{X}_c+p_2\tilde{Y}_c+p_3\tilde{X}_c^2+p_4\tilde{Y}_c^2+\ \ldots\ldots\ p_9\tilde{Y}_c^3$$

$$Y_d = q_0+q_1\tilde{X}_c+q_2\tilde{Y}_c+q_3\tilde{X}_c^2+q_4\tilde{Y}_c^2+\ \ldots\ldots\ q_9\tilde{Y}_c^3$$



E⃗ field behaviour near the screws holding the MCP stack together, the force exerted on electrons points away from them and towards the center of MCP

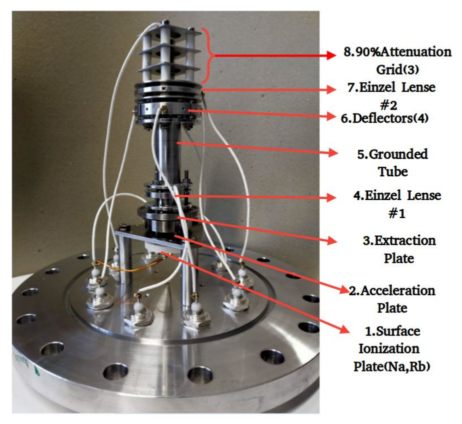
- The distorted edges in the construction of detector raw image are being identified as charge distribution in conductors in in the vicinity of the MCP plates leading to their polarization
- Considering the screws as point like charges and by taylor expanding the formulated E⃗ field expression, an important contribution from linear and cubic terms is noted than the quadratic terms.
- The symmetry of the electric field will suppress the even terms of the Taylor expansion, which also explains why the third-order correction produces better results than the precedent.

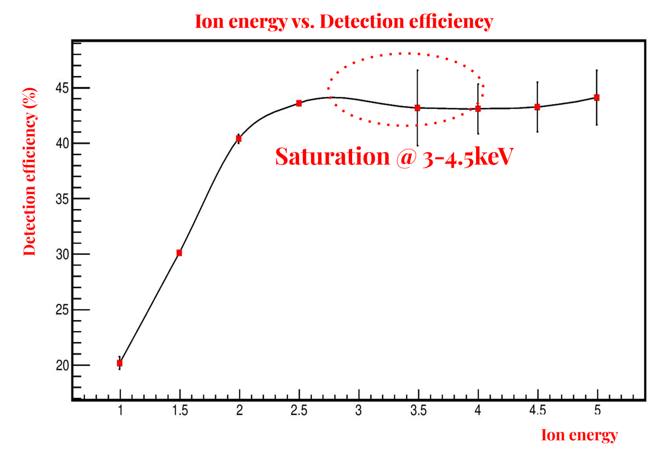


The fit yields a resolution 0.8 ± 0.4 mm in x and 0.9 ± 0.4 mm in y with a position accuracy of 80µm

Absolute efficiency measurement

- RIDE testings with surface ionisation (^{23}Na) pallet
- Homemade ion gun equipped with filament heating up at 4.5-5 volts, producing ions accelerating at 1.5keV hitting the front of MCP with 1.5-6 keV
- Behlke switch (±3kV) supply for creating pulses of 2 µs (t1) every 10ms of the cycle (t2) in 3 min of acq. time (T)
- Offline ion guide simulation using SIMION toolkit





$$|\varepsilon| = \frac{(MCP_{ions}-MCP_{background}).e.\mu_{att}}{FC_{avg}.d.T}$$

Detector efficiency scan with respect to the energy of the ions reaches maximum efficiency plateau at 45% validating the minimum tension for RIDE equivalent to -3kV, similar behavior has been observed also with delay line anodes[9]

First results from the online experiment

Last 3 phases of MORA experiment

Production mechanism: $^{24}Mg(p,d)^{23}Mg$

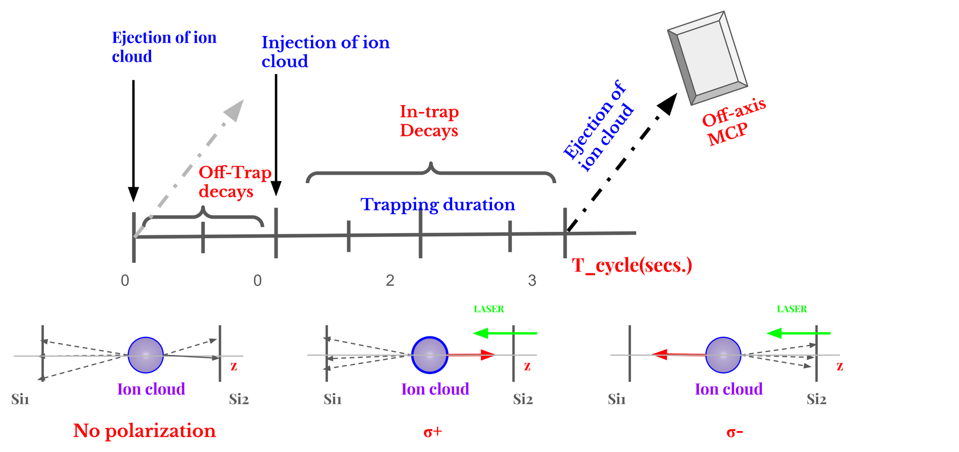
- 7 micro-Amps proton beam (10^5 ions/µA)
- Beam energy : 30 MeV

Major Contaminant: ^{23}Na

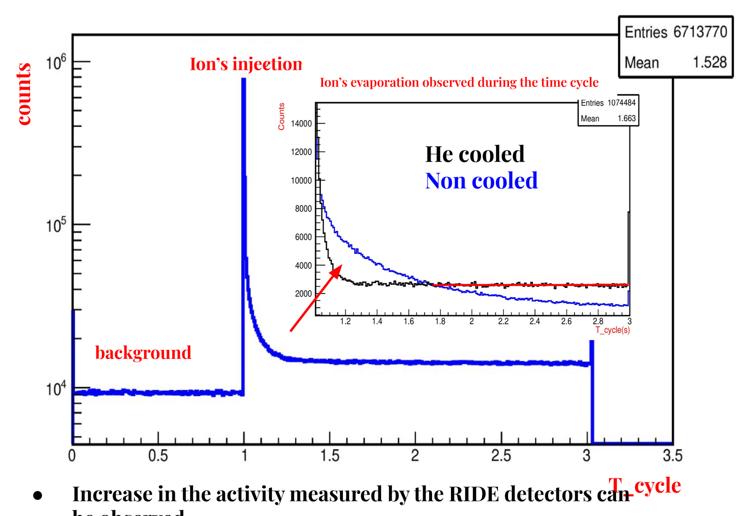
Ion-Bunching: endplate mode (20-100µs)
Minibuncher (500ns-1µs)

Trapping cycle:

- 1st phase : 500ms (5 - 50% efficiency)
- 2nd phase : 130ms (1-5% efficiency)
- 3rd phase: 3 sec (1-15% efficiency)



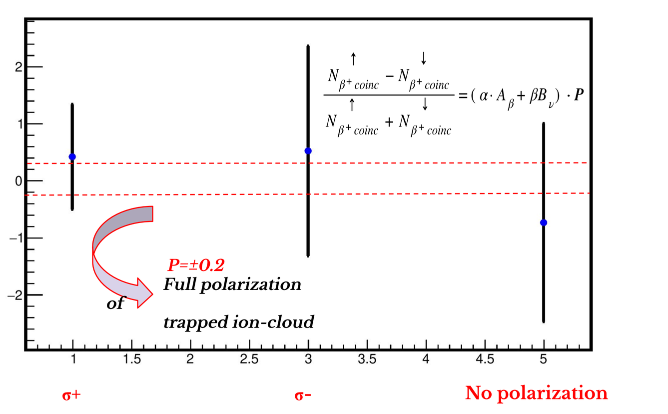
Confirmation of Trapping of Ions



- Increase in the activity measured by the RIDE detectors can be observed. (taken with He injection).
- Observed activity mainly due to ion cloud's evaporation than the recoils from the decay of ^{23}Mg ions.

First Polarization results from MORA

(statistically inconclusive)



- Another way of determining the P value is by assessing the observed coincidence with recoil ions which eventually helps to minimize the high background
- The symmetry an be reformulated as a linear combination of the β and neutrino asymmetry coefficients

Outlook

- Development of MCP based new recoil-ion detection system including position sensitive anode calibrated in position and employing the high order detector image reconstruction
- Maximum detection efficiency of 45% for ion's ranging from 3.5-4.5keV justifying the minimum biasing potential of -3kV
- First proof of ion trapping from RIDE activity during 3 hours of Polarisation(σ⁺,σ⁻) test
- No sizeable asymmetry determination due to insufficient beta- recoil coincidences
- Big scope of future improvement by implementing the longer trapping times, more ions trapped/bunches, much more purified ^{23}Mg beam

Acknowledgement

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