Refurbishment and characterization of the Miniball ionisation chamber

Summer student project report

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August 2024

1.Introduction

ISOLDE (Isotope Separation On-Line Device) [1] is a vital component of the CERN experimental complex. Established in 1967, ISOLDE's main function is to produce exotic and unstable radioactive beams that are utilized in a broad array of scientific fields, including nuclear and atomic physics, solid-state physics, astrophysics, and weak-interaction physics, among others. Radioactive isotopes are produced through spallation, fission, or fragmentation processes within a dense target, initiated by a 1.4 GeV proton beam from the Proton Synchrotron Booster (PSB). After production, the desired nuclei are ionized, extracted, and separated according to their mass using ISOLDE's two mass separators—the General Purpose Separator (GPS) and the High Resolution Separator (HRS). These separators generate the specific beam required, which can then be further accelerated and directed to various experimental setups. The HIE-ISOLDE upgrade enhances the energy and intensity, boosting the exotic nuclei to energies between 3-10 MeV/u, which can be used in Miniball, the experiment I am currently involved in.

The Miniball [2], a high-resolution germanium detector array, has been operational at REX- and HIE-ISOLDE at CERN for over two decades. This system includes 24 six-fold segmented, encapsulated high-purity germanium crystals, designed in a tapered configuration. It was specifically developed for experiments involving low multiplicity and utilizing low-intensity radioactive ion beams (RIB). The Miniball array has played a crucial role in numerous Coulomb-excitation and transfer-reaction experiments, utilizing exotic

RIBs with energies around 5 MeV/u, all produced at the ISOLDE facility. The array is depicted in Fig. 1.

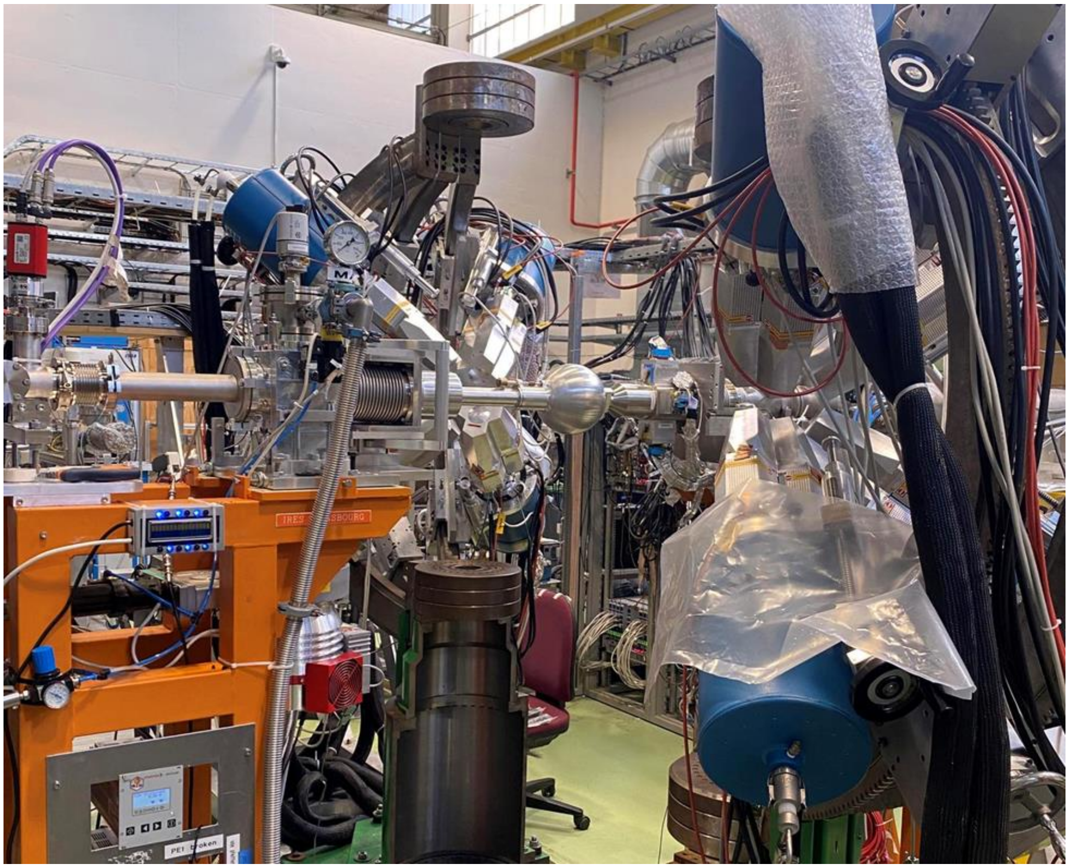


Figure 1 : The Miniball spectrometer.

The particle detector utilized for Coulomb-excitation experiments is a Double Sided Silicon Strip Detector (DSSSD). Typically, four quadrants of the DSSSD are used. This detector is designed to stop all heavy ions, whether beam-like or target-like, that scatter within the angular range covered by the DSSSD. It effectively handles all types of post-accelerated ion beams and reaction targets that have been used at HIE-ISOLDE to date.

Often the beam we receive in Miniball does not consist only of the isotope we want to examine. The primary sources of beam contamination include isobars generated in the target and particles with similar A/q ratios originating from the EBIS. Certain A/q values are particularly prone to contamination. For instance, selecting A/q=4 can lead to contaminants from the buffer gas within the EBIS trap, while A/q=3.6 is associated with a significant amount of ^{22}Ne, a stable beam commonly used for calibration purposes. In that case we want a way to determine the purity of the beam and to distinguish the different contaminants. The chosen approach to identify both stable and radioactive beam contaminants is a ionisation chamber.

2. The Miniball ionisation chamber

The Miniball ionisation chamber (IC) is mounted at the end of the beamline and serves as a ΔE – E detector [3]. It consists of a gas detector and a silicon detector at the end. The gas used in the detector is CF_4 (tetrafluorocarbon). The energy the beam loses in the gas volume is ΔE while the residual energy E is measured by the Si detector. The beam enters through Gate valve 2 (GV2). The IC configuration is shown in Figure 2. A 3D model of the chamber is shown in Figure 3.

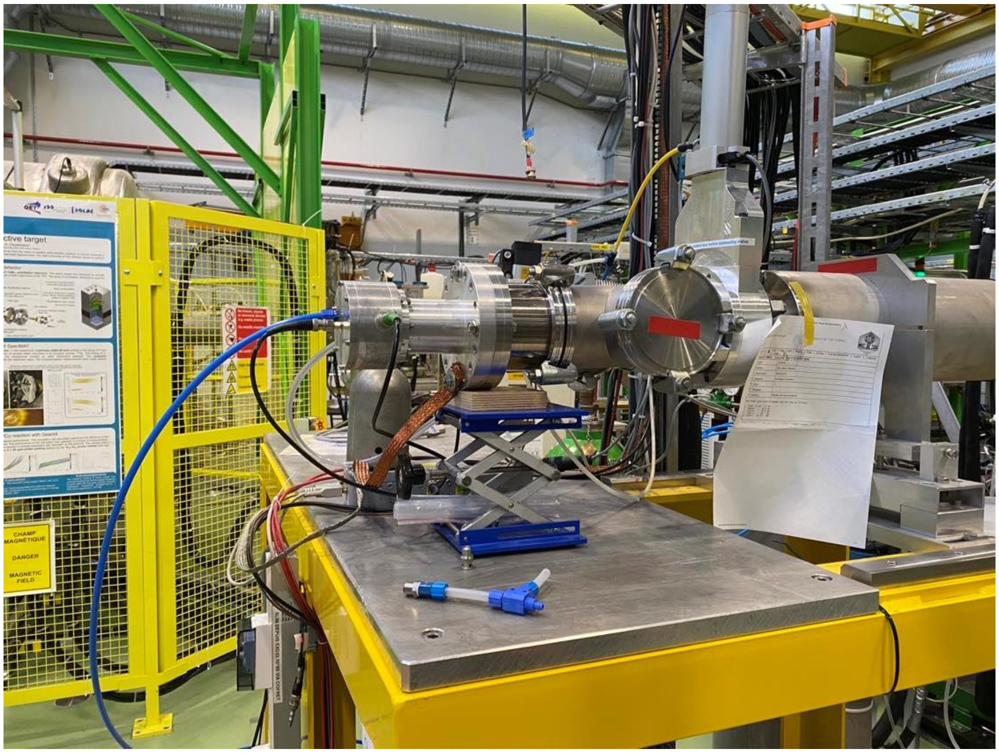


Figure 2: The Ionisation chamber.

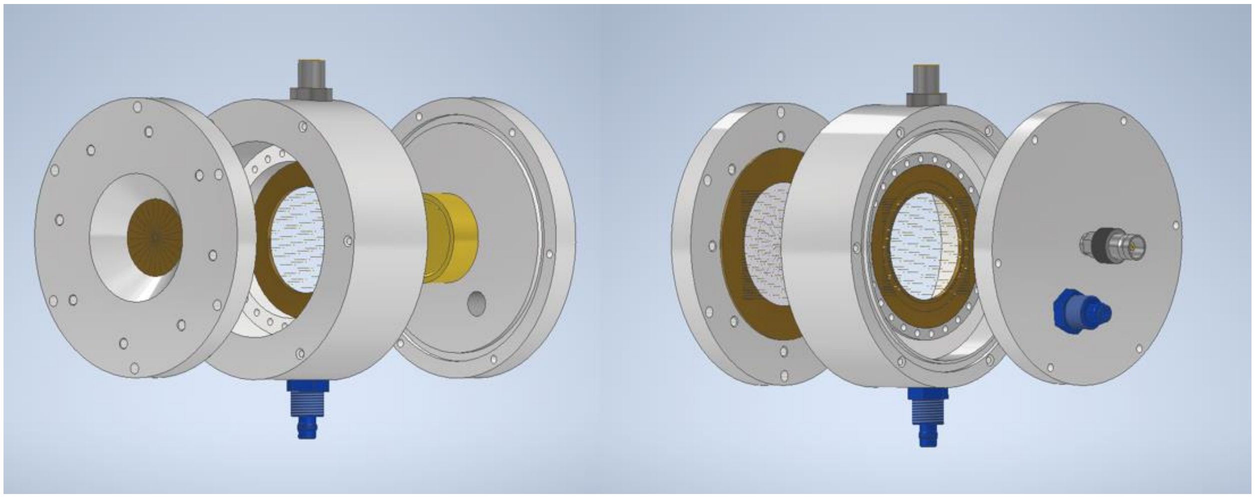


Figure 3: 3D model of the IC.

The parts of the IC are as follows:

- Pepper pot and aluminized mylar entrance foil with thickness 2 um (15 nm of aluminum on each side).
- An inactive gas region between the foil and the anode of the IC of 1 mm.
- The active volume gas detector (the distance between the anode and the cathode is 10 mm).
- Another inactive gas region with thickness 10 mm
- The Silicon detector

There are two ways the beam loses energy in the IC – electronic and nuclear. We don’t take into account the nuclear energy losses because they are relatively small. The electronic energy losses are caused by the ionisation in the gas. This can be explained by the Bethe equation, which depends on the energy of the particles (the same for all elements in the beam) and the term $\mathbf{q^2/A}$. Although the ions may have different charges, they generally align with their atomic number (Z), which gives us a useful Z-dependence. By applying voltage to the gas, we can collect a signal, whose strength will vary based on Z, helping us identify the element.

We can regulate the voltage on the Si and the pressure and the voltage of the gas. We have done some tests to determine the best values for these parameters in the subsequent chapters.

3. Repairing the Ionisation chamber

The first task I received for the summer student project was to repair the IC as it was not used properly for years. The reason is the anode and cathode mesh were broken due to incorrect venting of the chamber. **The pressure in the chamber should always be higher than the pressure in the beamline!** Thanks to Frank Browne and David and Andy from Manchester we received the new anode and cathode rings with freshly installed gold plated tungsten wire, 20um thick. I resoldered the cathode reinstalled the anode and (Figure 4 and 5). Dimensions of the rings are given in Figure 6 and 7.

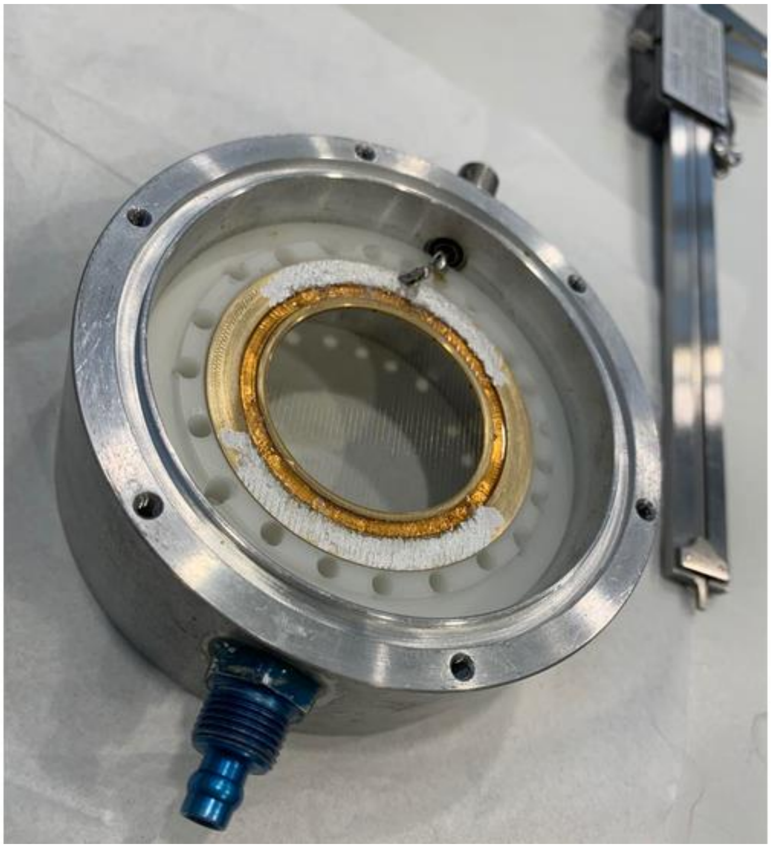


Figure 4: The anode of the IC.

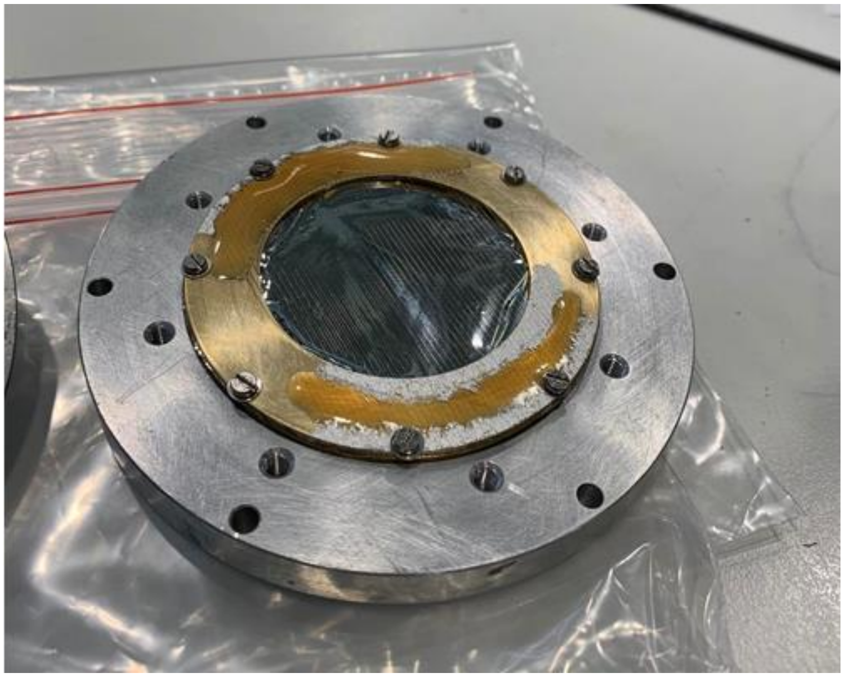


Figure 5: The cathode of the IC.

“Front view”

“Anode”:
Outer diameter: 60 mm
Inner diameter: 40 mm
Glue channel outer edge: 5 mm
Glue channel width: 3 mm
Pin hole: ~1 mm

“Cathode”:
Outer diameter: 68 mm
Inner diameter: 44 mm
Screw hole diameter: ~2.5 mm

Figure 6. Dimensions of the cathode and anode rings (Front view).

Side view

“Anode” thickness: ~2 mm (1.8mm
according to workshop...)

“Cathode” thickness: 1 mm

Figure 7: Dimensions of the anode and cathode rings (Side view).

We also removed a valve that caused a vacuum leak while we were testing the chamber. The purpose of this valve is to prevent the chamber from going above atmospheric pressure, in case the gas regulation system fails and the bottle of CF_4, which is under high pressure, goes directly to the IC. The probability of this happening during an adequate operation of the IC is really small, so we removed the valve and brought it to a CERN valve workshop for testing. The test result is given in Fig. 8. It shows that the valve is rated at 0.25 bar above atmospheric pressure (1.25 atm). The valve is shown in Fig. 9.

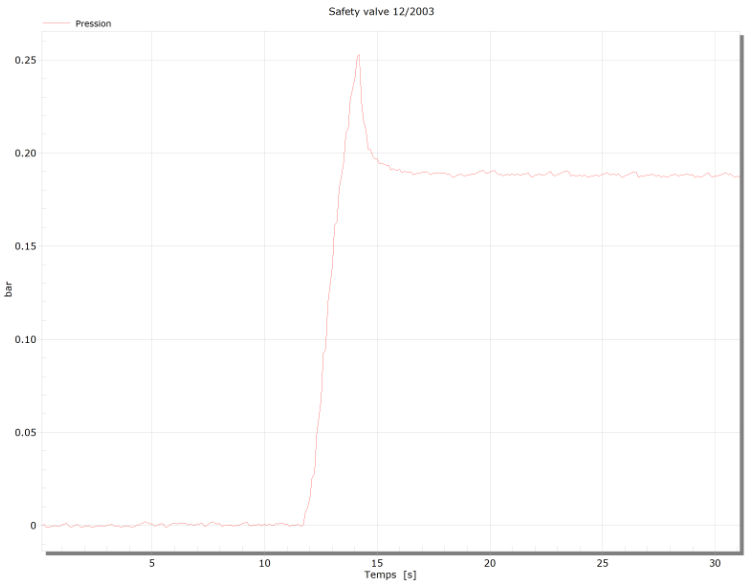


Figure 8: Safety valve pressure test.

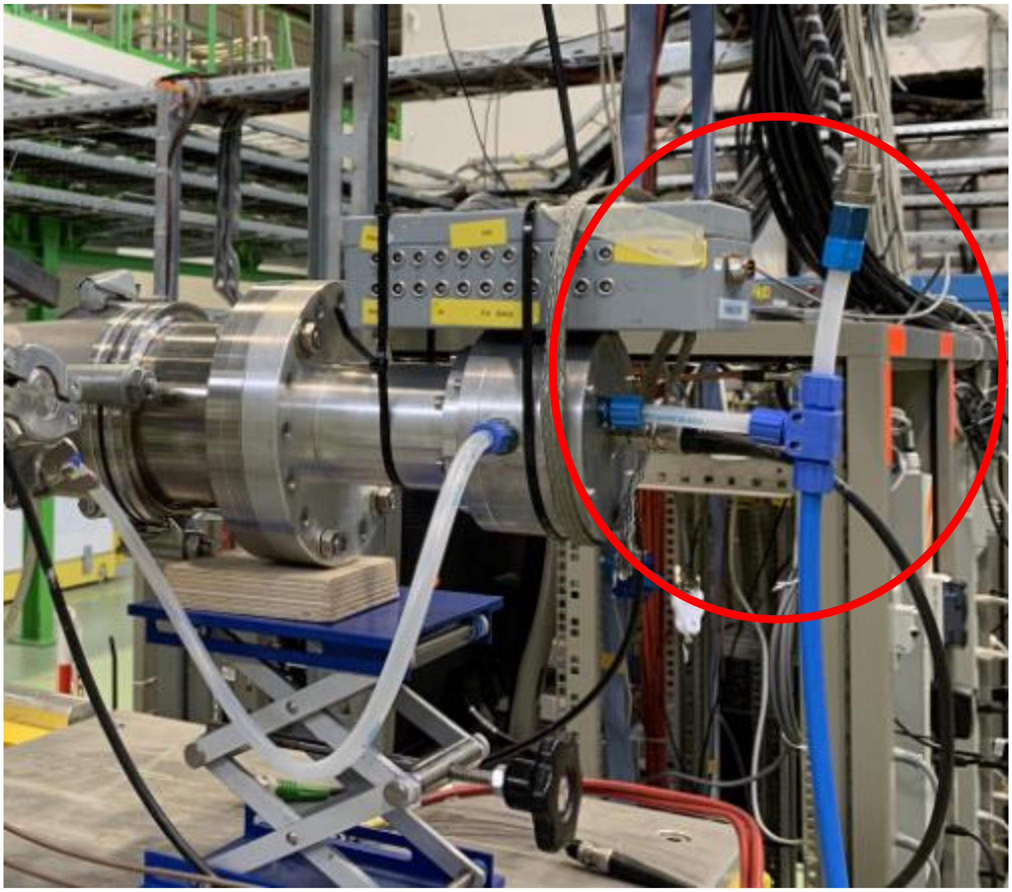


Figure 9. Safety valve.

4. Silicon detector test

The Si detector is crucial for the operation of the IC as it detects the residual energy – E. Since it wasn't used for a long time, we decided to do some tests to determine its condition. Miniball also has a spare Si detector which we also tested. For the test, I had to determine the optimal operating voltage by building a I-V curve. As the voltage increases, the leakage current also increases and ideally we should see a plateau which corresponds to the optimal voltage we want to use. Unfortunately, the test showed no plateau, which indicates both detectors are damaged as they have been irradiated by beam during experiments for many years. We finally decided to use the first Si, as it looked better than the spare one in the subsequent tests we did. The voltage we chose was 200 V, as it was the highest that we could use. The I-V curves of both detectors are shown in Fig. 10 and 11.

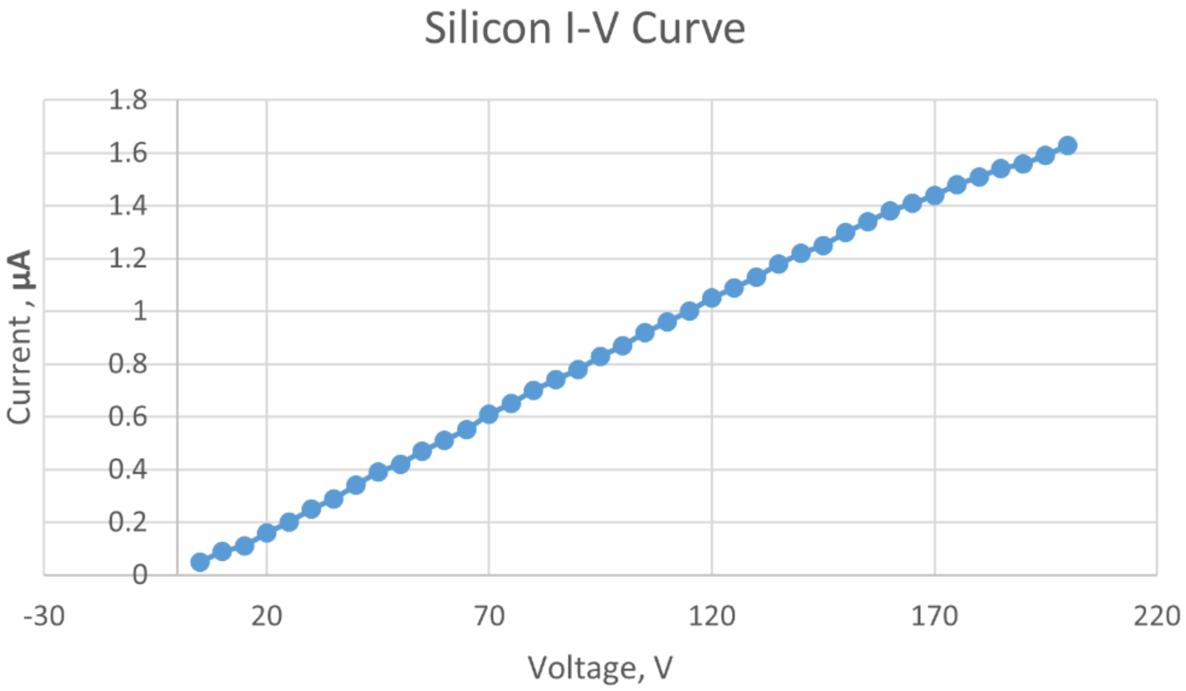


Figure 10: I-V curve of the main Si detector.

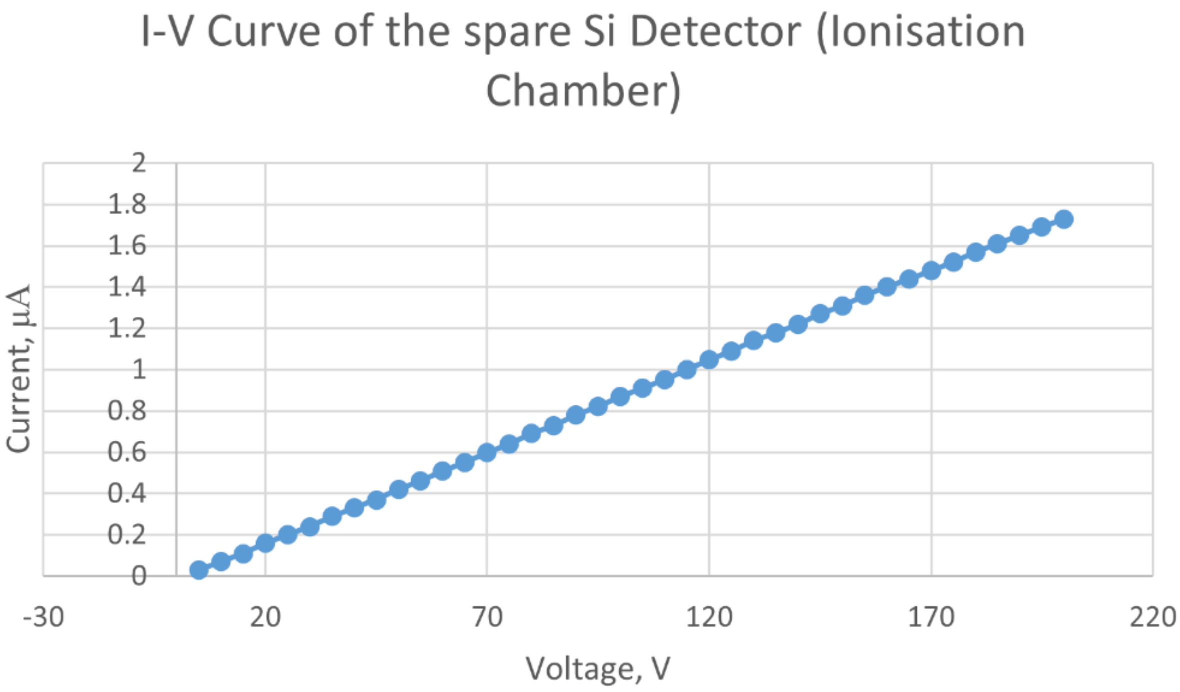
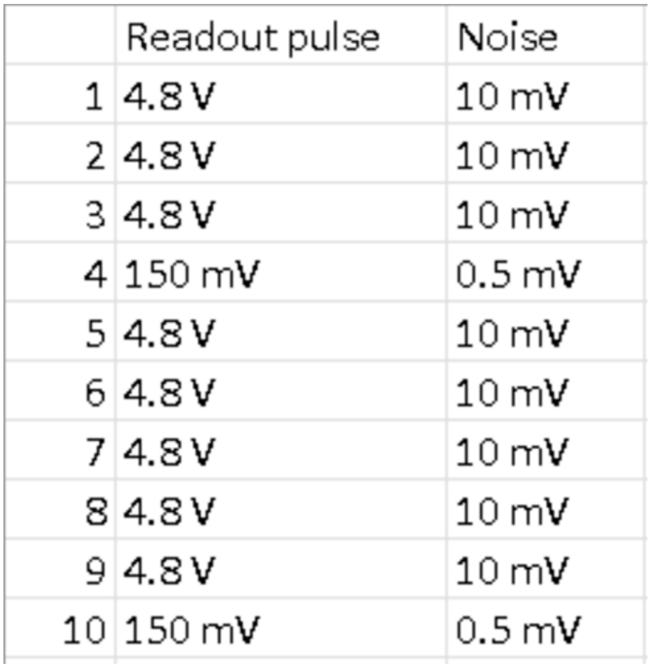


Figure 11: I-V curve of the spare Si detector.

5. Preamplifier box test

The next step of our IC testing was to determine the gain of every channel of the preamplifier. In order to do that we connected a pulser to a capacitor in order to imitate a detector. We have 400 mV from the pulser connected to a 15 pF capacitor which creates 6 pC current. Then we took note of the voltage from the readout channels of the preamplifier box (Figure 12).



	Readout pulse	Noise
1	4.8 V	10 mV
2	4.8 V	10 mV
3	4.8 V	10 mV
4	150 mV	0.5 mV
5	4.8 V	10 mV
6	4.8 V	10 mV
7	4.8 V	10 mV
8	4.8 V	10 mV
9	4.8 V	10 mV
10	150 mV	0.5 mV

Figure 12: Preamplifier box readout channels voltage.

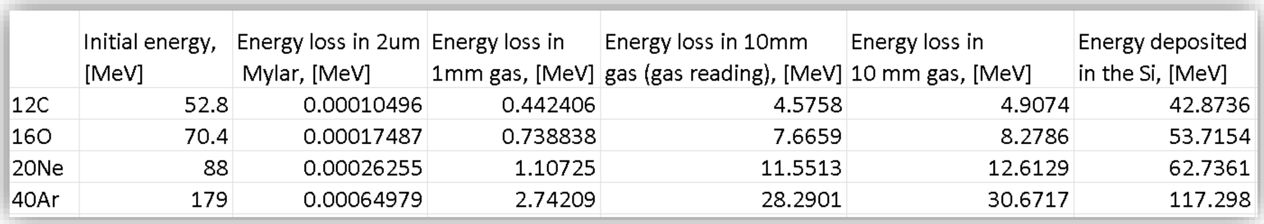
According to our test, Channel 4 and 10 are the low gain channels and their noise is about 0.5 mV. Channels 1, 2, 3, 5, 6, 7, 8, 9 are the High gain channels and their noise levels are approximately 5-10 mV. During real experiments channel 4 is used for the Si detector and channel 1 for the Gas detector.

6. Stable beam tests

At HIE- ISOLDE there are stable beam tests every year in order to make necessary calibrations and tests of the experiments. In our case, we received stable beam consisting of stable isotopes with A/q = 4. The beam contained isotopes of 4 different elements with energy 4.4 MeV/u – ^{12}C, ^{16}O, ^{20}Ne and ^{40}Ar. For our measurements we used the following parameters:

- 200 V for the of the Si detector.
- 250 V for the gas detector.
- 500 mbar for the pressure,
- x300*300 = x90000 beam attenuation.

The only parameter that depends on the characteristics of the beam is the pressure. The heavier the beam the less the pressure should be. Beam attenuation is needed because the Si detector stays right in front of the beam and would be highly damaged by a very intense beam. In order to calibrate the Si and the gas detector I did simulations with the SRIM software and used a code Ben Jones provided me. Table with the energy losses in every subsequent part of the IC is shown in Fig. 13.



	Initial energy, [MeV]	Energy loss in 2um Mylar, [MeV]	Energy loss in 1mm gas, [MeV]	Energy loss in 10mm gas (gas reading), [MeV]	Energy loss in 10 mm gas, [MeV]	Energy deposited in the Si, [MeV]
12C	52.8	0.00010496	0.442406	4.5758	4.9074	42.8736
16O	70.4	0.00017487	0.738838	7.6659	8.2786	53.7154
20Ne	88	0.00026255	1.10725	11.5513	12.6129	62.7361
40Ar	179	0.00064979	2.74209	28.2901	30.6717	117.298

Figure 13: SRIM energy loss table for the 4 stable beam isotopes (^{12}C, ^{16}O, ^{20}Ne, ^{40}Ar)

The values that we are the most interested in from Fig.13 are the gas reading and the energy deposited in the Si, as these should correspond to the energy peaks in our spectra. The spectra of the gas and Si are shown below in Fig.14 and 15.

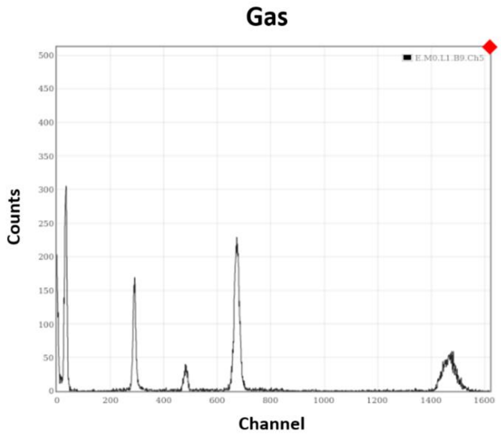


Figure 14: Gas spectrum.

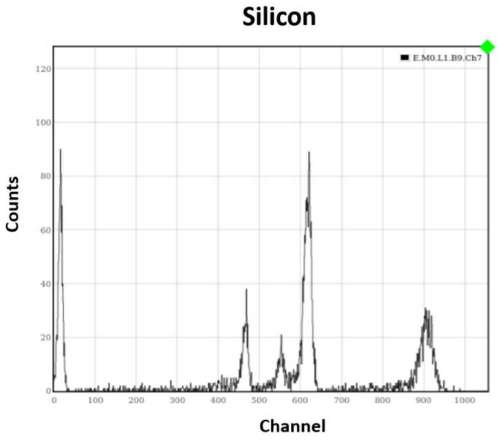


Figure 15: Si spectrum.

The gas spectrum looked a lot better than we expected. That showed that the rewinding of the golden wire grid was a huge success. The Si detector shows signs of damage, but we can still differentiate the 4 peaks in both spectra. We see another low energy peak really close to 0 in the raw data, which we were not sure if its noise or 4He, but after the calibrations it ended below 0.

After using the 4 points for calibrating the detectors, the linear calibration can be seen on Fig. 16 and 17.

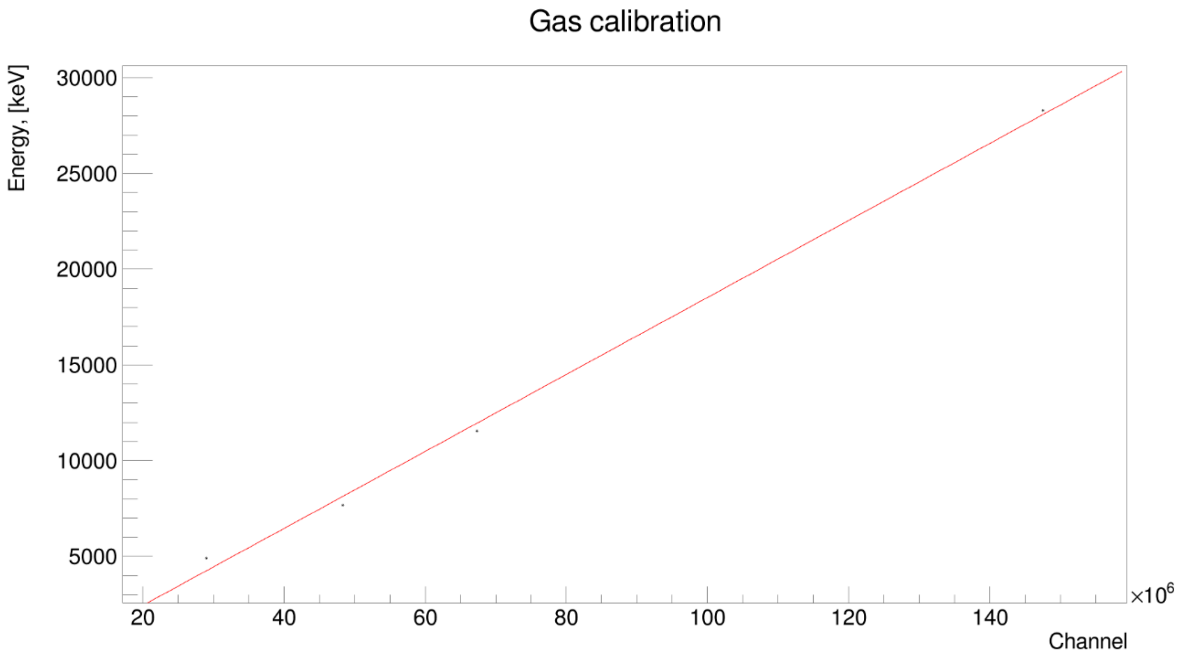


Figure 16: Gas calibration, linear fit.

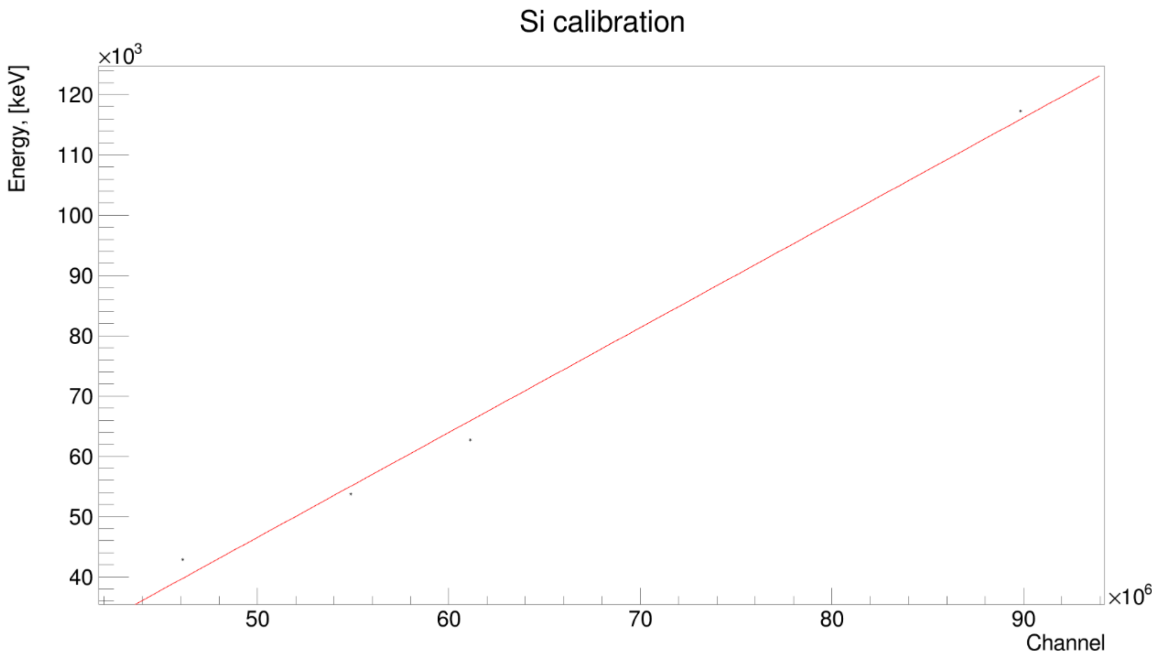


Figure 17: Si calibration, linear fit.

The last step of our analysis is to observe the 2D spectrum combining the gas and Si spectra. We can clearly distinguish our 4 isotopes of interest. By measuring the counts in each “blob” we can determine the relative intensity of each of the contaminants and consequently the purity of the beam.

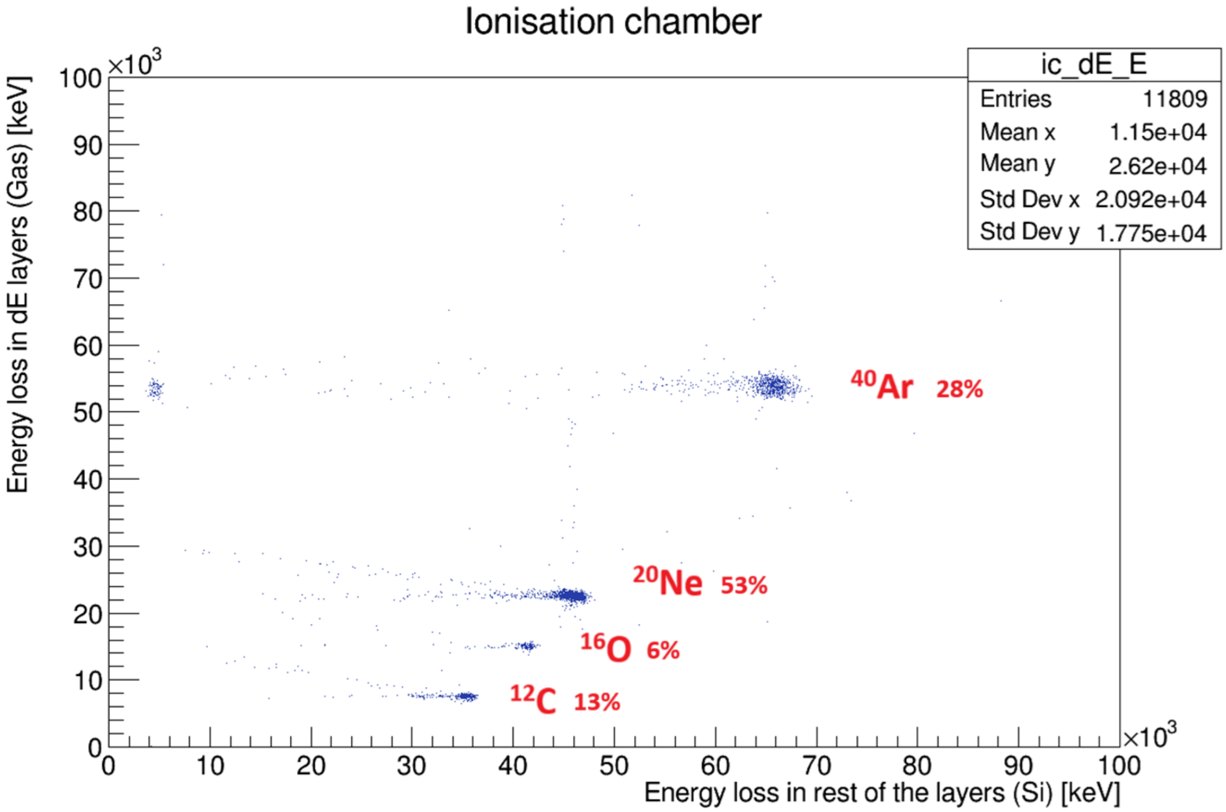


Figure 18 : 2D ΔE–E plot of the stable beam

8. Runs during experiment IS647

During my stay I had the opportunity to test the IC with radioactive ion beam during the IS647 experiment. We used $^{79}Zn^{20+}$ beam with energy 4 MeV/u and A/q = 3.95. As I mentioned in Chapter 1, contaminants can originate from EBIS as particles with similar A/q ratio. That is why we see the A/q = 4 contaminants, although we have A/q = 3.95 (shown in Fig. 19).

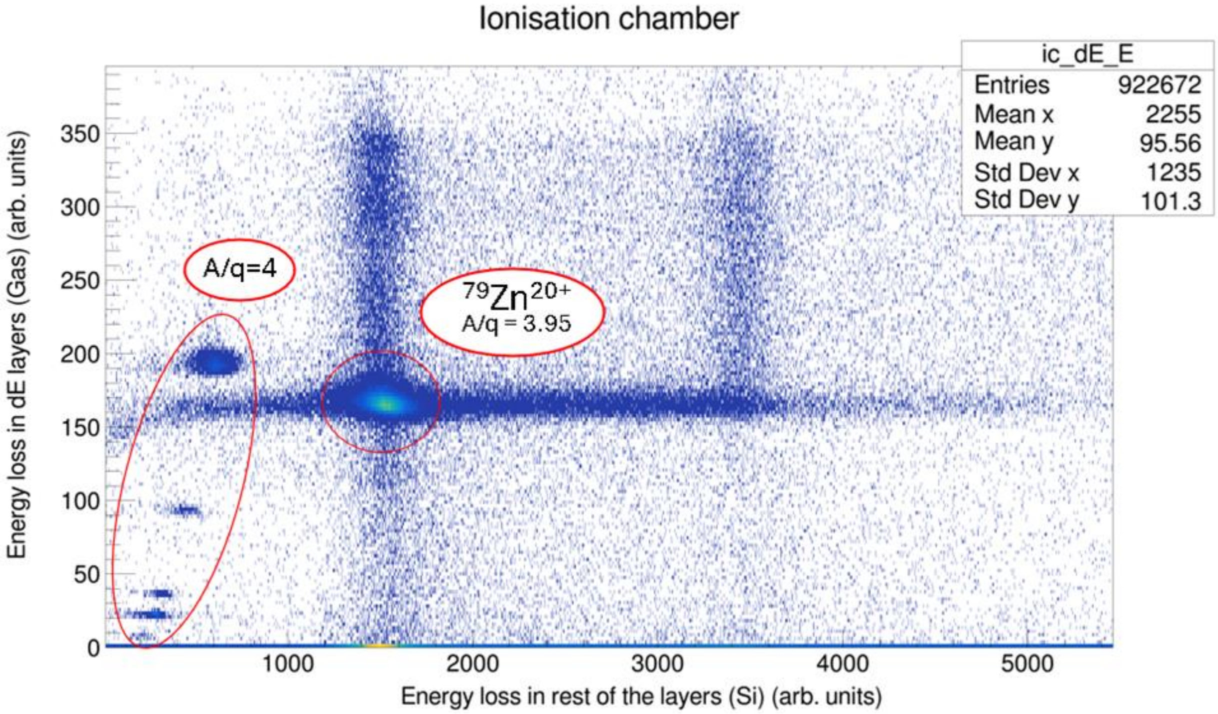


Figure 19: 2D ΔE–E plot of ^{79}Zn Radioactive ion beam.

We also observed a dependence between energy loss in the gas and the gas flow, as illustrated in Figure 20. Specifically, as the gas flow increases, the energy loss in the gas also increases. This can be explained by the fact that higher gas flow introduces more fresh atoms into the system, providing more opportunities for ionisation, which in turn leads to greater energy loss.

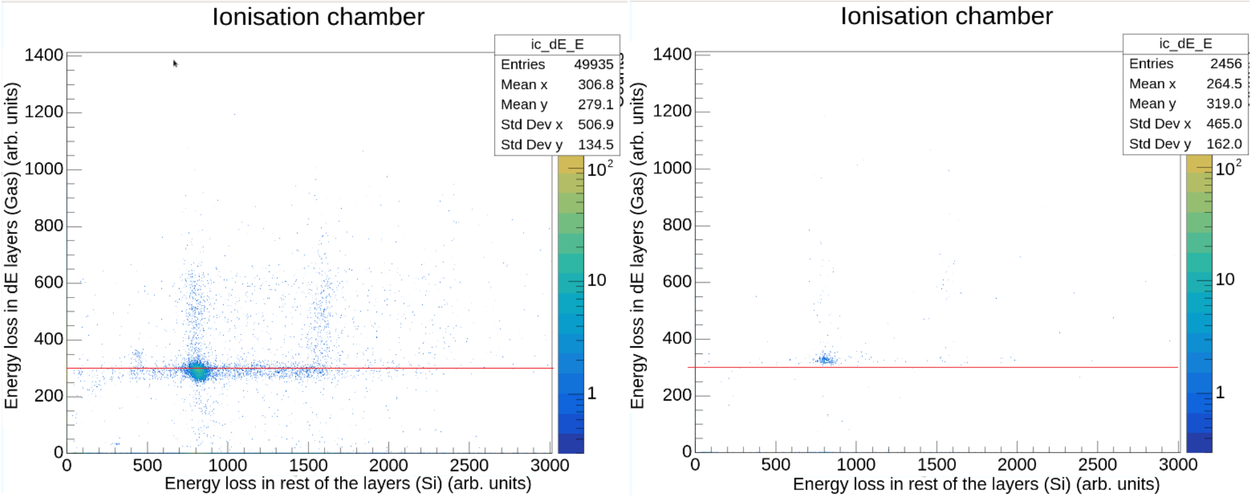


Figure 20: Difference in energy loss in the gas, slower flow (left), faster flow (right).

9. Summary and conclusion

Since the chamber had not been operated in its original design since 2011, we needed to thoroughly test every component, including the gas regulation system, preamplifier, and Si detector, among others. We encountered issues with almost all of the components, but we successfully resolved each one. After these repairs, we tested the chamber using both stable and radioactive beams, and the results were highly promising.

I would conclude that the project was successful. While the Ionisation Chamber may not be a critical component of the Miniball setup, if operated correctly, it can serve as a valuable tool for upcoming experiments.

Bibliography

[1] ISOLDE Facility, https://isolde.cern/isolde-facility.

[2] N.Warr, The Miniball spectrometer, Eur. Phys. J. A 49, 40 (2013).

[3] N. Warr, Ionisation chamber, https://apps.ikp.uni-koeln.de/~warr/doc/ion_chamber.pdf