Ionisation Chamber

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May 2017

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1 Introduction

The beam provided by REX-ISOLDE often has one or more contaminant isotopes, which are not desired for the experiment. There are several sources of such isotopes:

- isobaric contaminants produced in the ISOLDE target or due to in-flight decay, which have the same A. The volatile the contaminant, the more likely it is, so noble gases can easily appear as such contaminants.
- contaminants with an integer multiple of the desired A produced in the ISOLDE target or due to in-flight decay, which pass through the HRS or GPS separator with the same A/q as the singly charged ions. e.g. with the GPS set to A = 96, we got ^{96}Kr and ^{192}Hg.
- contaminants with a similar A/q which come from the REXTRAP and/or EBIS. This is particularly the case of stable neon (used as buffer gas in the trap), but we have also had ^{139}La from the lanthanum boride electrodes of the EBIS.
- contaminants due to ions, which pass through the HRS or GPS separator as a molecule having the same A as the desired ions, then break up and have a similar A/q to the setting on the REX separator (or the othe way around) e.g. with the GPS set to A = 166 to select ^{132}Sn+^{34}S as a molecule and the REX separator set to A/q = 4.258 to get ^{132}Sn^{31+} we also got ^{166}Yb^{39+} with A/q = 4.256.

The A/q contaminants depend on the elements present in the trap and EBIS and the setting of the magnets and slits. Typically we expect an A/q resolution of about 0.02. However, there are some slits at the base of the separation magnet which can be used to restrict this. Some values of A/q have high levels of contamination. For example, A/q = 4 has ^{4}He^{+}, ^{12}C^{3+}, ^{16}O^{4+}, ^{20}Ne^{5+}, ^{40}Ar^{10+}. The first three are present in what little air remains after the EBIS is pumped to high vacuum and the noble gases come from the buffer gas in the trap, which is primarily neon, but with other noble gases as well. Also A/q = 3.6667 has a huge amount of ^{22}Ne^{6+}, which we often use to calibrate the positions of the Miniball detectors using the (d,p) reaction on deuterated polyethylene. There are many other such peaks in the mass scan and there is usually a plot of the scan in the control room.

The HRS and GPS separators can select a particular A (assuming the ions are only singly charged) but cannot distinguish between different isobars. Usually, ion sources are carefully chosen to enhance the element of interest and suppress the main contaminants, but the suppression of contaminants is not usually 100 %. Note also, that some of the newer ion sources have a higher ionisation efficiency, which gives a better yield of singly-charged ions, but also gives doubly charged ones.

Consequently, we need to be able to determine the beam composition. The ionisation chamber can be used for this purpose. Note, that there is also a Bragg chamber, which uses similar methods, but in a more sophisticated way, but this cannot reliably separate isobars for values of Z over about 40. It is also more complicated to set up. Consequently, the Bragg chamber hasn't been used for years.

2 The chamber

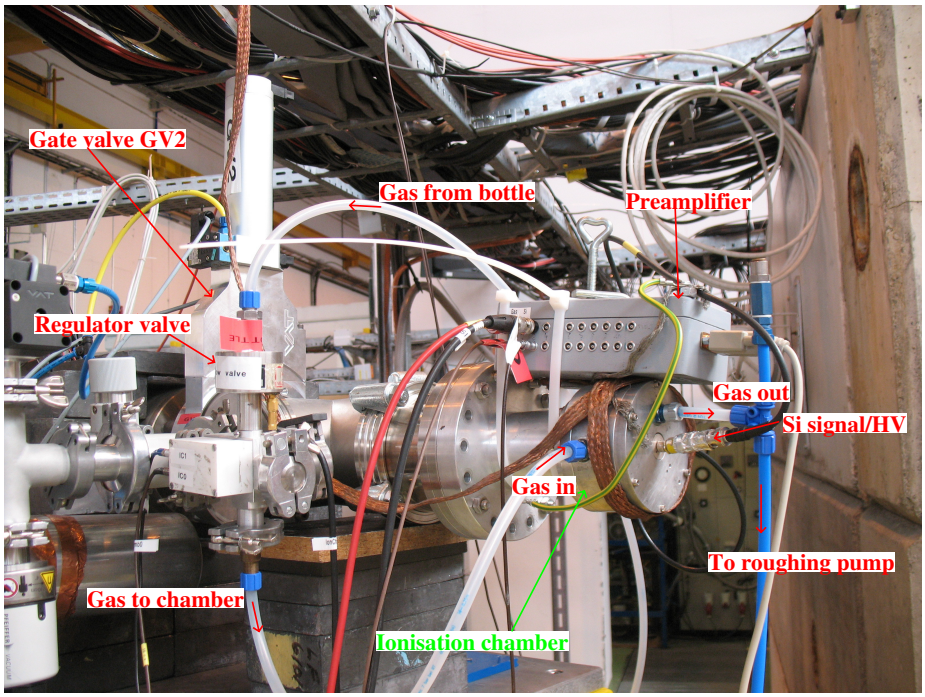

Figure 1: The ionisation chamber with the preamp above it

The ionisation chamber consists of:

- a 2 μm thick aluminised mylar entrance foil (15 nm of aluminium on each side)
- a volume of CF_4 gas about 2 mm thick (Dennis gives 1.45 mm)
- a 2 μm thick aluminised mylar cathode foil (15 nm of aluminium on each side)

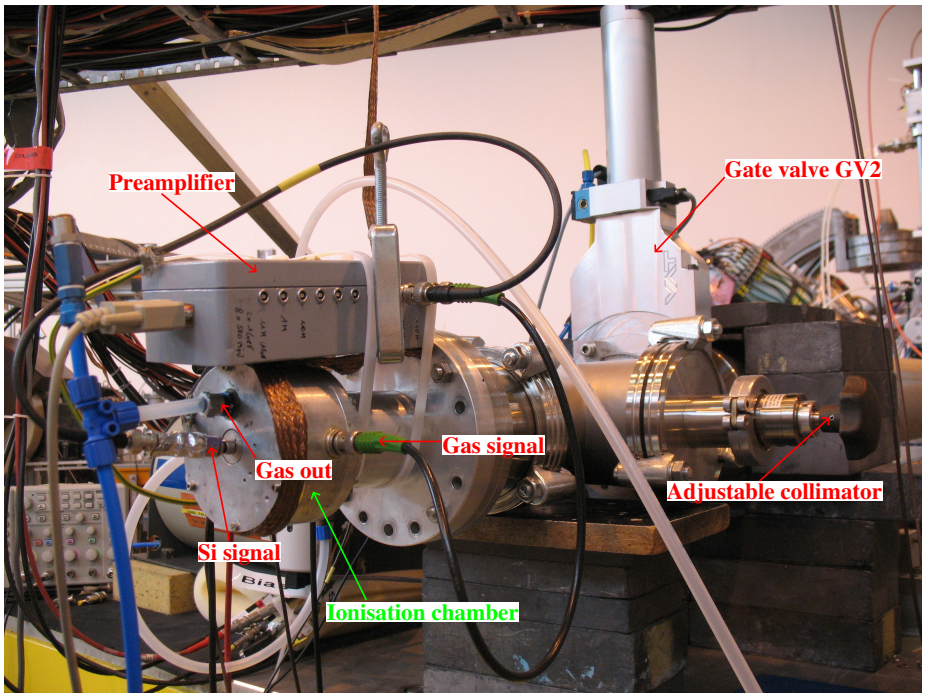

Figure 2: The ionisation chamber with the preamp above it. Note that the adjustable collimator now has a bellows.

- a volume of CF_4 gas about 1 cm thick, in which we detect the energy loss (Dennis gives about 18.25 mm)
- an anode mesh[1]
- a volume of CF_4 gas about 1 cm thick (Dennis gives 15.25 mm)
- a Si detector about 300 μm thick with which we detect the residual energy. (Dennis says it protrudes about 13 mm into the previous gas region, so the effective thickness of that gas region is only a couple of mm).

Dennis gave some additional information:

- The chamber is in three parts. The first and last parts are each about 10 mm and the middle part about 37 mm.
- There is a supporting mesh in direct contact with the first foil.
- Both the first and second foils are 2 μm double-sided aluminized Mylar. The first one acts as an entrance window and the latter as cathode.

[1] The anode is not an aluminised mylar foil as was previously thought!

- There is 1.45 mm between these foils, which makes an inactive volume of CF_4.
- The Si detector sticks out 13 mm from the back of the chamber, so the total gas volume covers a distance of 35.2 mm.
- The anode is a grid which looks like it is in the middle of the middle piece. i.e. 28.5 mm from the front and back faces. This would then be 15.25 mm from the surface of the Si or 18.25 mm from the cathode.
- This implies we have 1.45 mm inactive gas region, then 18.25 mm active gas region, then 2.25 mm inactive gas region and finally the Si detector and then a further 13 mm inactive gas region around the Si detector but downstream of the active part.

Note, therefore, that we have inactive gas volumes (2mm and 10 mm - or 1.45 mm and 2.25 mm according to Dennis) so the total energy is not given by the sum of the Δ E and E_{rest}.

The idea is that the incoming ions lose energy in the gas, producing a signal, the amplitude of which is proportional to the energy lost. As the stopping powers depend on Z, this gives a Z dependence.

Often, people look at the A/q = 4 beam from the EBIS to check out the ionisation chamber. However, one should be aware that most beams during experiments have isobars, so the critieria for separating them are a bit different.
Note, that this assumes that the ions have the same energy per nucleon, which is normally the case for Miniball experiments. However, if you look at the signals on the ionisation chamber when there is a target in the target position, this will change the charge state by stripping, so you won't have the same relationship as without a target, though this effect is probably small, as we likely reach some equilibrium part way through the gas.

The ionisation chamber was originally designed to use P10 (90% argon and 10 % methane), but CERN safety rules have forbidden this, so we now use CF_4.

Note that in 2011, the foils were destroyed in a vacuum incident. They should be replaced in April 2012 in Munich. The new foils may be different from the ones indicated here, so please check the correct information!

There is a pepperpot foil just in front of the ionisation chamber, which can be adjusted from outside. This is better than the old collimation slit we had, but it still produces scattering. There is, however, now a second pepperpot just after the A/q separation from the EBIS (i.e. before the accelerating elements of REX). This is much better, because scattered ions don't have the right energy to get through the bending magnet.

Previously it was possible to rotate the pepperpot foil, which resulted in more scattered beam. In 2017 it was modified, so it can only go in straight. Also it now has a bellows, so there is no risk of breaking the vacuum, when moving this foil.

3 The parameters

The main parameters to play with are the gas pressure and the voltage across the gas. Note that the NIM module can only regulate up to 750 mbar!

In 2009, we did some extensive tests with it and found a gas pressure of 350 mbar and a gas voltage of +300 Volts to be quite good for A $\approx$ 100. It may be possible to optimize this further, but we have some standard base values for these settings, so it is probably easier to use these settings, in order to be able to compare directly.

The idea is to have the particles lose about half their energy in the gas and half in the Si. If you are looking for A/q contaminants, you probably want to have this criterion valid for the middle of the range of charge states that you have. On the other hand, if you are looking for isobars, it is probably better to have this criterion for the isotope of interest. Pressures from 300 to 500 mbar seem OK.

We also have about +50 Volts on the silicon detector.

For the test measurements described here, we used the following parameters in 2011:

Parameter	Value
Gas	CF_4
Thickness of first inactive gas region	1.45 mm
Thickness of active gas region	18.25 mm
Thickness of inactive gas region	2.25 mm
Gas pressure	300 mbar
Gas voltage	+300 Volts
Si voltage	+50 Volts

Roman has an emirical formula for the optminal gas pressure:

$$p = 1000 \times \frac{30}{Z\_proj} \times \frac{1.57}{3.69} = \frac{12764.228}{Z\_proj}[mbar]. \quad (1)$$

So 300 mbar is about right for molybdenum, but this value seems fine for krypton and cadmium as well. For heavier ions, you might want to lower the pressure a bit.

The CF_4 gas can be ordered via EDH using SCEM code 60.56.10.110.5 but this is not stocked at CERN, so delivery can take (theoretically) up to 3 months. Probably it is a lot less, but don't wait for the bottle to be empty before ordering more!

4 The electronics

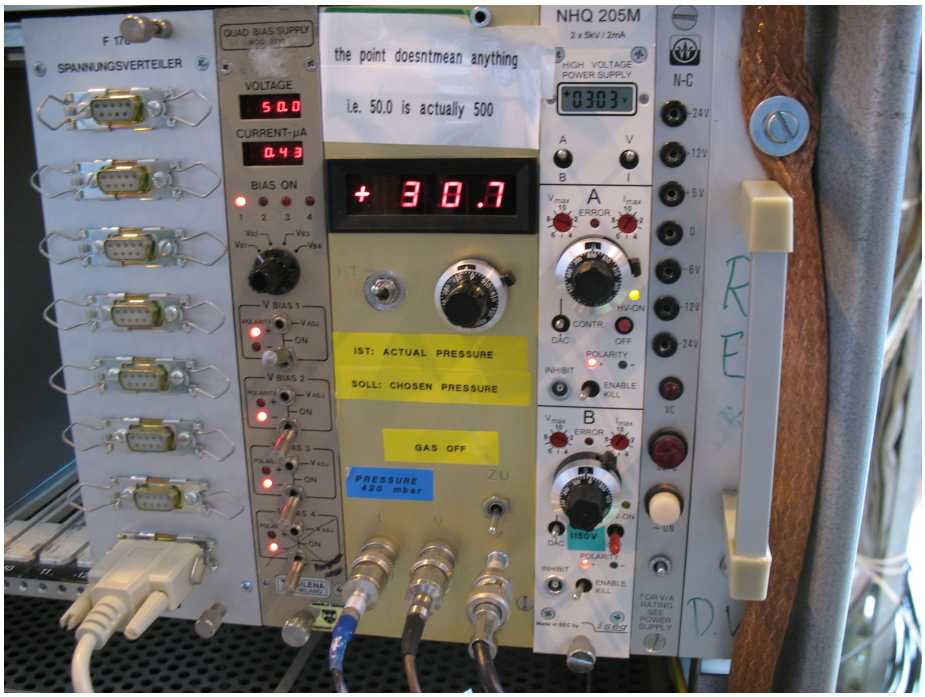

Figure 3: The electronics in the rack near the beam dump. Note the display on the gas regulator shows +30.7, but this really means 307 mbar. In this photograph, the voltages on both the Si detector (the Silena module on the left) and the Gas (the top half of the NHQ 205M module on the right) are typical values. The bottom part of the NHQ 205M is not used.

The electronics are quite simple. There is an output from the gas detector at the side, which goes into the first channel of the preamplifier and an output from the Si detector at the back, which goes into the second channel. We check the outputs of these signals on the oscilloscope to make sure we don't have too much pile-up. There is an adjustable pepperpot (see figure 2), which can be adjusted to reduce the beam if there is too much pile-up.

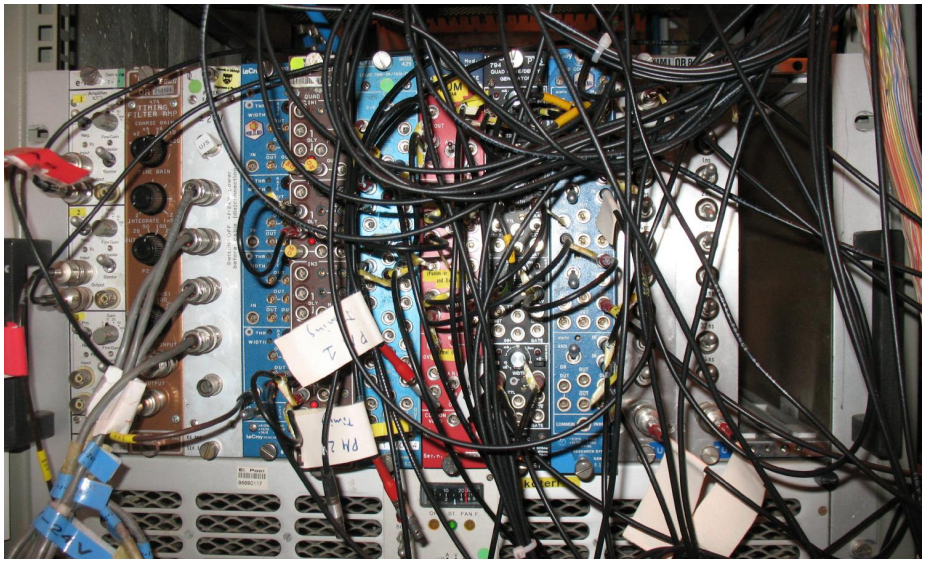

Figure 4: The electronics in rack 1. Only the first, second and fourth modules are used for the ionisation chamber. Note that the slot in between has a broken +6 Volt pin, so the discriminator will not work in that slot. The module in there is a 24 Volt supply for the PAD preamps, which doesn't need +6 Volts and has nothing to do with the ionisation chamber. The other modules are all T-REX modules and are not actually plugged in.

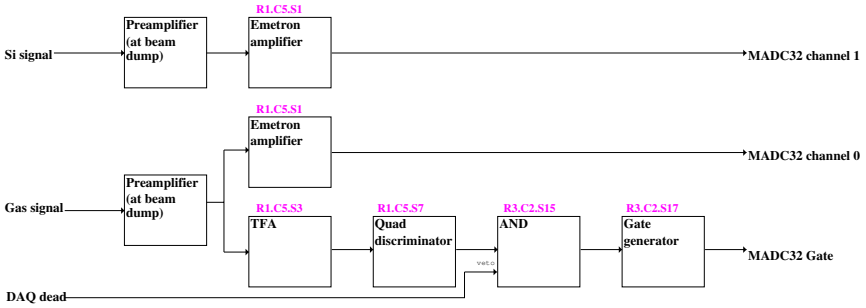

Figure 5: The ionisation chamber electronics.

The two signals go to the Miniball rack. The gas signal is split there using a T-piece and one copy goes into a TFA and from there into a discriminator and then into a gate generator to generate the gate on the MADC32. The other copy goes to an Emetron amplifier and from there into the first channel of the MADC32. The Si signal goes to a different channel of the same Emetron amplifier and from there to the second channel of the MADC32.

5 The gas system

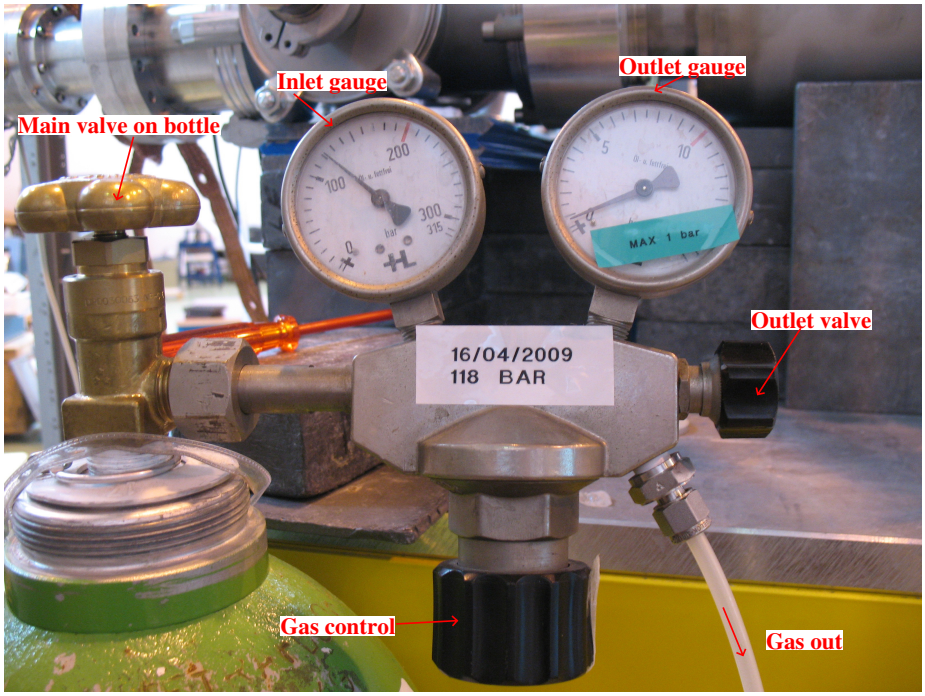

Figure 6: The valves at the gas bottle

The gas flows from the CF_4 bottle, which has a large knob to open up the gas from the bottle to the manual regulator, then the manual regulator has a small knob to adjust the output pressure (see figure 6). There are two gauges, one showing the pressure coming out of the bottle and the other showing the output pressure. The former should be of the order of 50-300 bar (this indicates how much gas is in the bottle, so if it is lower than this, the bottle is empty!), while the output pressure should be of the order of 0.8 bar and **must** be below 1 bar.

From the manual regulator, a plastic tube goes to an electronically controlled flow regulator (shown on figure 1) and from there into the side of the ionisation chamber. The gas flows out of the back of the ionisation chamber to a roughing pump via a needle valve (see figure 7).

The idea is that we pump on the chamber from one side and the electronic regulator lets in gas at an appropriate flow in order to maintain the desired pressure in the chamber. Obviously, the pumping must not be too strong that the flow out of the gas bottle is insufficient to compensate it. However, enough pumping is needed to ensure a flow of gas. The needle valve on the roughing

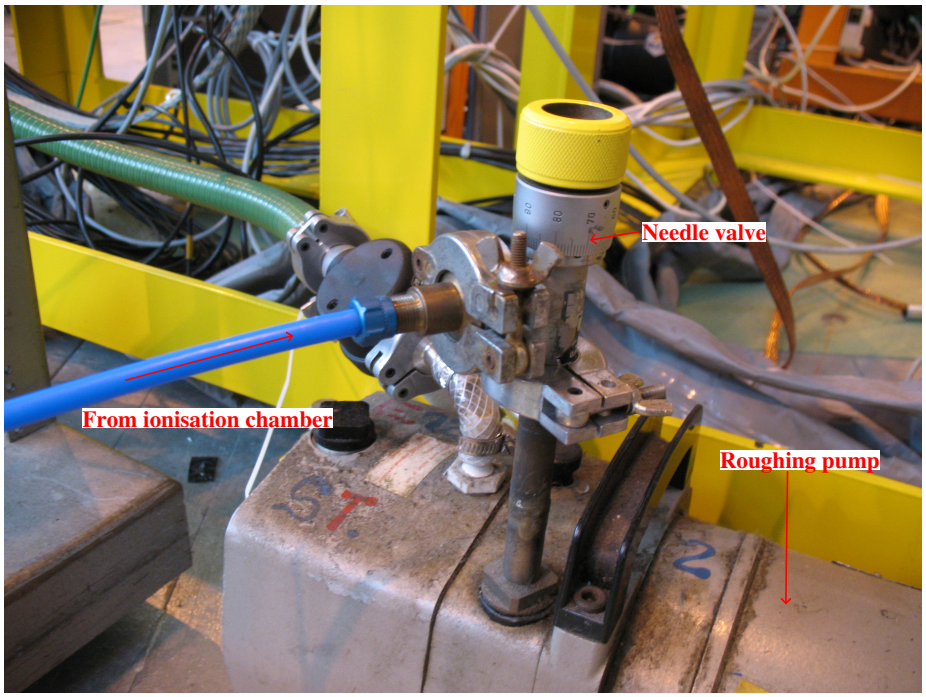

Figure 7: The needle valve at the roughing pump

pump is used to regulate the pumping.

The electronic regulator is controlled by a double width NIM module made by Munich, which sits in the rack near the beam dump (see figure 3). It is very simple to use. You set the switch to "SOLL" and dial up the desired pressure ("soll" means "should" in German) and then set it to "IST" ("ist" means "is") to see the current value. It also has a switch for which one position is labelled "ZU" (means "closed"). In this position, the electronic valve between the gas bottle and the ionisation chamber is closed, so the chamber is still being pumped on, but no gas can enter. In the other position, which is labelled "V", the valve is opened and closed automatically in order to maintain the desired pressure in the chamber. Note that when it first starts regulating, it goes first above then below the desired value, oscillating a bit, before converging on the correct value.

Note that the display shows tens of millibar, not millibar! So just pretend the decimal point isn't there!

6 The vacuum system

The ionisation chamber is separated from the beam dump by a thin mylar window. There is a gate valve (GV2) which can separate the beam dump from the main beam line. There is also a bypass valve (BV4) which is used to connect the roughing pumps to the beam dump. There is also a vacuum gauge labelled "BEAMDUMP" below the NIM regulator module in the electronics rack near the beam dump, which shows the pressure in the beam dump.

The controls for BV4 and GV2 are also in that rack (at the top). There is also a "manual" switch on that control unit for BV4. If the vacuum is better than 2E-2 mbar in the beamdump, you cannot open the bypass valve BV4. Normally, you only have such a good vacuum in the beam dump if the gate valve is open and you are pumping with the turbo pumps, so you don't want to open the valve to the roughing pumps. In manual mode, that is the only condition, but if manual mode is not selected, BV4 won't open if the vacuum in the main beam line is better than 5E-1 mbar. This is another safety feature. So if you have high vacuum in the main beam line, you need to switch to manual in order to rough down the beam dump.

When you have good vacuum in the beam dump and the main beam line, you can close the valve between Miniball and REX (this is now only possible in expert mode from the ISOLDE vacuum controls), close BV4 (to stop roughing down) and open GV2 (to connect the main beam line to the beam dump) and when the vacuum is good, you may open the valve to REX again.

7 Dependence of gas signal amplitude

The amplitude of the signal in the gas is proportional to the energy an ion loses in the active part of the gas. However, we also have a small inactive region before the active one and another one between the active region and the Si detector. So the relationship between the amplitude of the gas signal and Z is not so simple.

8 Operation

8.1 Pumping down

- Set the lower switch on the control unit to "ZU".
- Set the upper switch to "IST".
- Close the needle valve between the roughing pump and the ionisation chamber.
- Turn on the roughing pump.

- Open the needle valve slowly.

8.2 Putting gas in

- Start with the roughing pump pumping the ionisation chamber via the needle valve and the lower switch on the control system set to "ZU" with vacuum in the ionisation chamber.
- Switch the upper switch to "Soll" and set the desired pressure. Then set it to "IST".
- Adjust the needle valve, so that it is pumping a bit, but not too much.
- Open the gas bottle to just under 1 bar.
- Switch the lower switch on the control module to "V".
- The control unit should then open the electronically controlled valve between the gas bottle and the ionisation chamber and the pressure should start to rise up to the desired pressure. If it does not rise, maybe you have the needle valve to the roughing pump open too far.
- When it reaches the desired pressure, it will overshoot a bit, then come back down and undershoot, oscillate a bit and eventually stabilise at the desired pressure.
- Then you can turn on the gas high voltage and the Si high voltage.

8.3 Taking gas out

- Turn off gas high voltage.
- Turn off Si high voltage.
- Set lower switch on control unit to "ZU". The roughing pump will then pump out all the gas.

8.4 Venting

- Make sure the gas is out and all the high voltages are off.
- Close the needle valve between the roughing pump and the ionisation chamber.
- Disconnect the needle valve from the roughing pump, so that the needle valve is still connected to the ionisation chamber.
- Slowly open the needle valve to let air into the chamber.

Important: the ionisation chamber can withstand a pressure of about 1 bar greater than the pressure in the beam line, but will be damaged or destroyed if the pressure in the beam line is greater than that of the ionisation chamber.

So always vent the ionisation chamber before venting the beam line! Also, always pump down the beam line first!

When not in use, you should vent the ionsiation chamber, so that if the vacuum in the beam line fails, it won't destroy the ionisation chamber.

9 Data acquisition

Previously, the ionisation chamber had a separate version of Marabou, running in a different directory. This is no longer the case. Now it is fully integrated into the main version of the DAQ. In principle it is possible to acquire with the ionisation chamber at the same time as with Miniball. Note, however, that if a target is in place, the stripping of the ions by the target will change the charge state, which changes the q^2/A rate. Energy loss in the target also changes the initial energy on entering the ionisation chamber. So the energy loss in the gas and Si detector will be different to those without a target. Nevertheless, it may be useful to detect changes in beam composition during an experiment (particularly when used with the laser ionisation source).

10 Analysis

In the past, we tried to understand the ionisation chamber by using LISE++ to calculate the energy loss and comparing this to experiment. However, it seems that the geometry of the detector was incorrect. So this did not work.

Vinzenz Bildstein has written a script *IonChamber.sh* to use the *irma* code to do the calculation directly from the command line. However, this also used the incorrect geometry. Also there seem to be quite big discrepancies in the stopping powers between LISE++ and this script. This script is on pcepis41 in the */home/miniball/vinzenz* directory. However, you should not rely on irma. It is an old code and is based on old stopping power data. It should be good for protons or even alphas on various materials, but the reproduction of data for heavy ions is poor. Use LISE++/SRIM.

More work is needed on this to understand it fully!