

# HIE-ISOLDE

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# 1 Introduction

This document is based on my original notes from 2007. Much has changed since then and I am probably not aware of all the changes. Some instrumentation is regularly updated (sometimes during experiments!) so this document can only be an approximate guide.

I've tried to update as much as I can, but there are some things, which I am sure are still wrong. For example, the names of the valves on the REX line, will have changed. I'm sure they are no longer V1 to V6 but will have the standard naming convention. Since the valve represents the transition between two sections, it is not clear if it takes its section name from the previous or the next section!

# 2 Naming convention

The naming convention changed during the long shutdown, though it remains fairly similar. First comes the section code:

Section	Meaning
XSEP	REX separator
XRFQ	REX RFQ
XLIHS	REX IHS
XL7GP	REX 7 gap
XL9GP	REX 9 gap
XLN2	Beam line from 9-gap to first cryomodule
XLH0	First cryomodule
XLN3	Beam line from first to second cryomodule
XLH1	Second cryomodule
XLN4	Beam line from second cryomodule
XT00	Beam line after superconducting LINAC
XT01	First experimental beam line (Miniball)
XT02	Second experimental beam line
XT03	Third experimental beam line

This is used to make up the code for the specific device:

Code	Meaning
A7GP	REX 7-gap resonator
A9GP	REX 9-gap resonator
ABUN	REX buncher
AIHS	REX IHS
AQH	High- $\beta$ cavity
AQL	Low- $\beta$ cavity
ARFQ	REX RFQ
BBO	Beam observation
BDB	Beam diagnostics box
BFC	Faraday cup
MB	Magnetic dipole
MC	Magnetic steerer
MQ	Magnetic quadrupole
ML	Solenoid
VVGS	Vacuum gate valve
VVFS	Fast acting valve (< 20 ms)
ZBE	Electrostatic bender
ZQP	Electrostatic quadrupole
ZQS	Electrostatic steerer

The first letter of these codes indicates the type of equipment. The following list gives the most important ones.

Letter	Meaning
A	Acceleration unit / RF
B	Beam diagnostics
M	Magnetic unit
Q	Cryogenics
V	Vacuum
Z	Electrostatic unit

Finally, there comes a number, which is generally incremented in hundreds, but if an additional element is inserted, it might only go up by 50 or even 10.

### 3 ISOLDE

The ISOLDE facility uses the 1.4 GeV proton beam from the PS-booster (four rings which can be operated independently) at CERN to bombard a target and produce a wide range of isotopes. Ions are extracted in a  $1^+$  state (possibly as molecules) and separated using one of two separators: the high-resolution separator (HRS) and the general-purpose separator (GPS).

#### 3.1 Ion sources

Chemistry plays an important role in the extraction of these species and a variety of techniques have been developed to enhance the extraction of particular

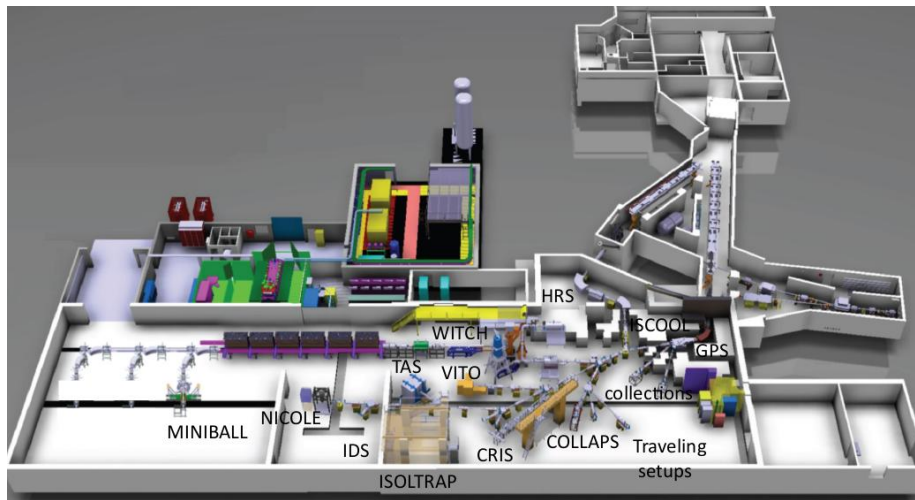


Figure 1: Layout of the ISOLDE facility

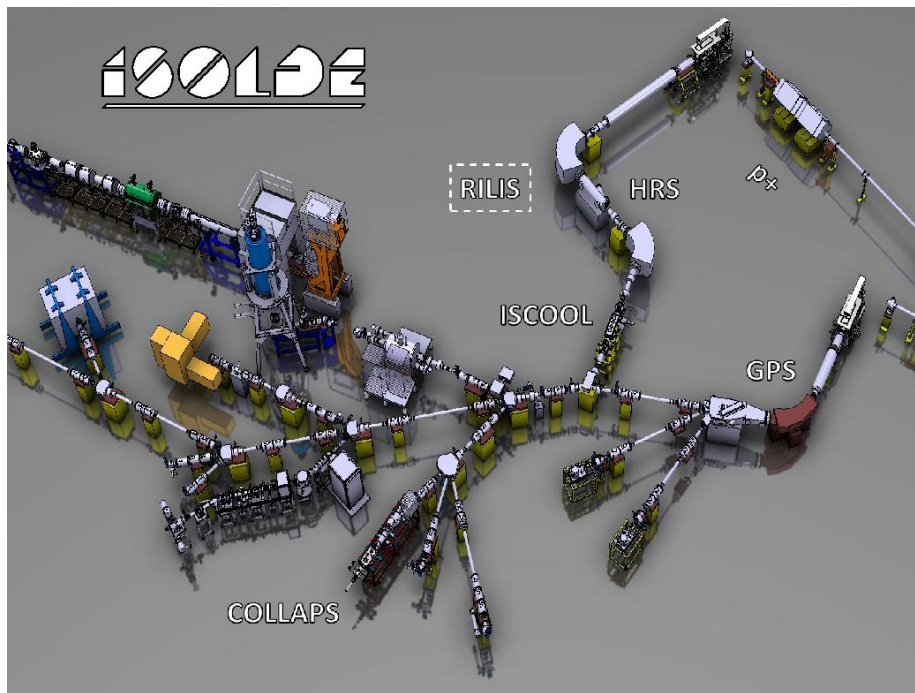


Figure 2: The ISOLDE target area showing the two primary targets at the right, and the two separators (HRS and GPS). The beam lines join to the common beam line and then branch out to the different experiments. The REX beamline is the one going to the top left.

species. Consequently different ion sources are used, depending on the species of interest.

- Surface ioniser
- Hot plasma source
- Cold plasma source
- Laser ion source

### 3.1.1 The Surface Ion Source

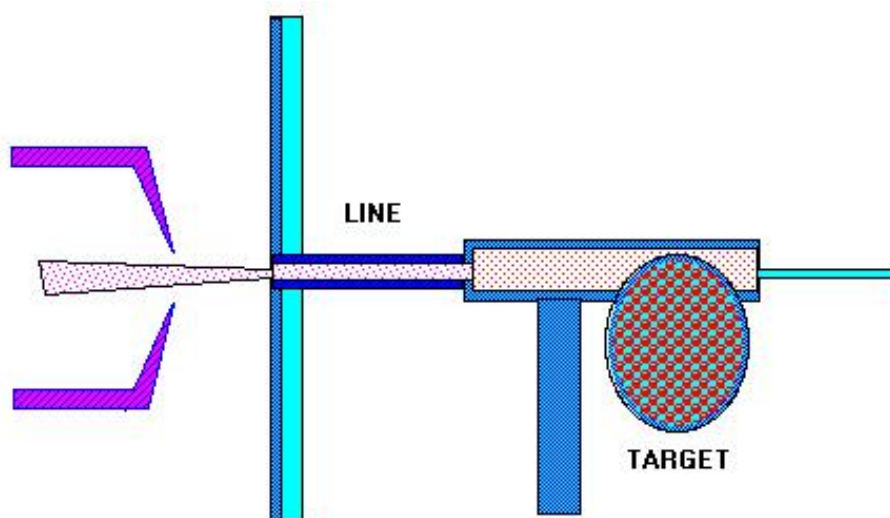


Figure 3: The surface ion source

The surface ion source is the simplest set-up for ionizing atoms produced in the target. The ionizer consists only of a metal tube ("line"), for example tantalum or tungsten, which has a higher work function than the atom that should be ionized. Depending on the line's material it can be heated up to 2400° C. Surface ion sources have been used in combination with most of the different target materials.

### 3.1.2 Hot Plasma source

The plasma ion source is used to ionize elements that cannot be surface-ionized. The plasma is produced by a gas mixture (typical Ar and Xe) that is ionized by electrons being accelerated between the transfer line and the extraction electrode by supplying an anode voltage of about 130 V. For the optimization of this process an additional magnetic field is used (SRCMAG). Plasma ion sources have been used in combination with most target materials.

### 3.1.3 Cold Plasma Source

For the production of noble gas isotopes the set-up has been modified in the way that the transfer line between target and gas plasma is cooled by a continuous

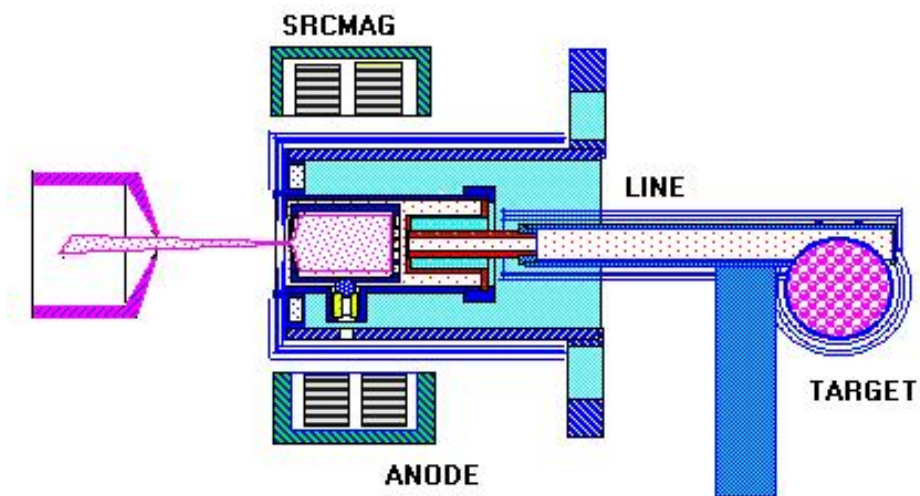


Figure 4: The hot plasma ion source

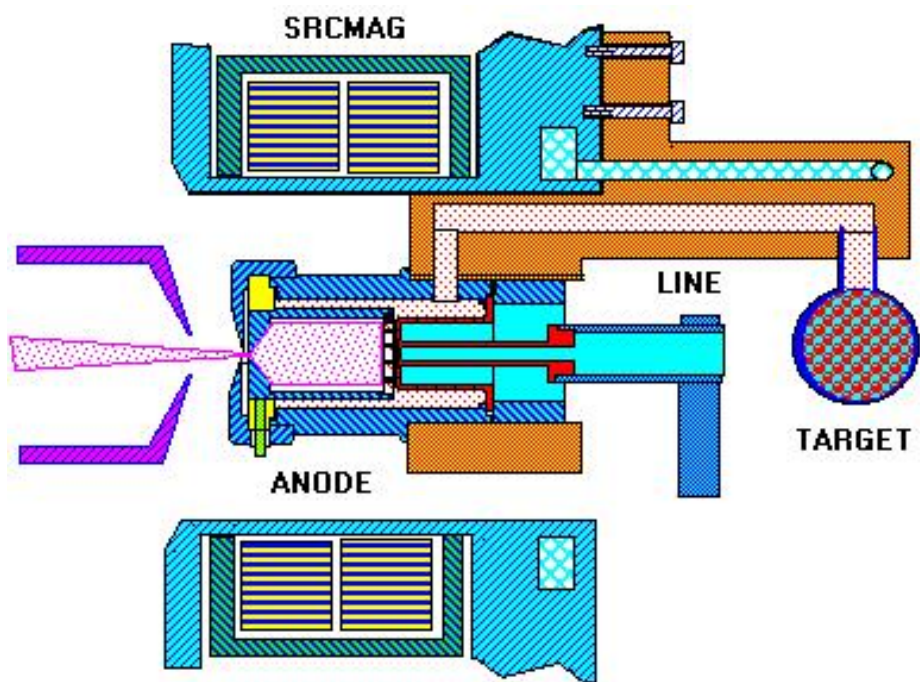


Figure 5: The cold plasma ion source

water flow to suppress the transport of less volatile elements and reduce via this mechanism the isobaric contamination in the ISOLDE ion beams.



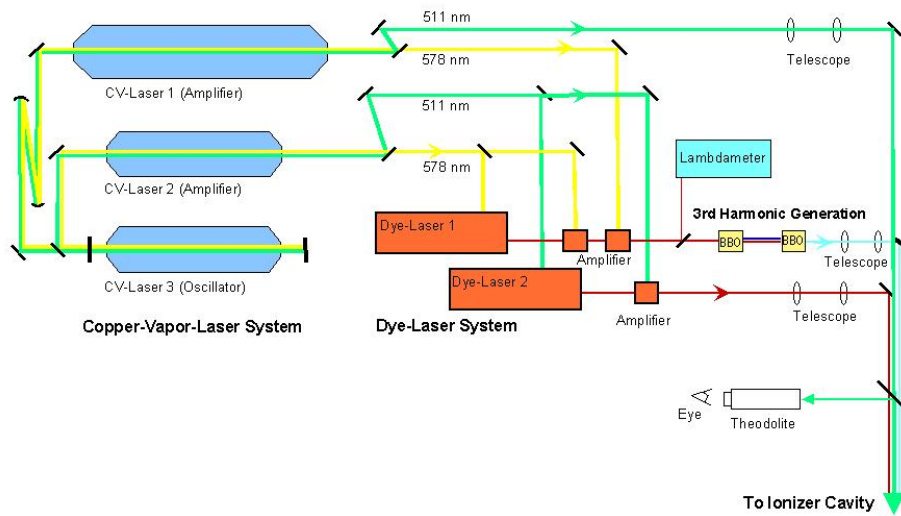


Figure 6: A schematic diagram of the laser ion source (RILIS)

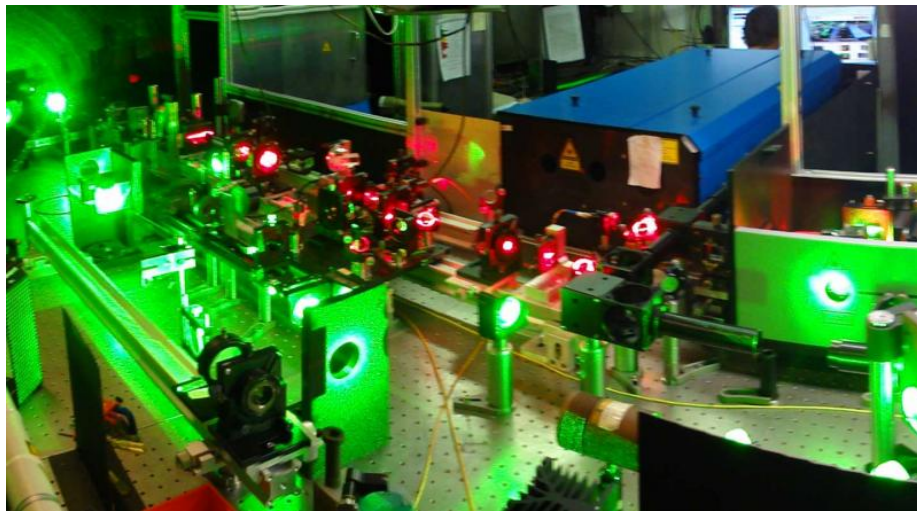


Figure 7: A photograph of the laser ion source (RILIS)

### 3.1.4 The Laser Ion Source (RILIS)

Another technique which is used is the resonance ionisation laser ion-source (RILIS) where a laser beam is tuned precisely to the energy of an atomic excitation in the element of interest and a second laser beam is used to excite an electron from that excited state into the continuum, thereby ionising the atom. Since only the ions of a given element are influenced by the first beam and the second one doesn't have enough energy to excite an electron from the ground state to the continuum, only atoms of the selected element are ionised. In fact, the RILIS facility at ISOLDE can use three beams, going through two intermediate states for further selectivity. The laser system consists of copper



vapour lasers, tuneable dye lasers and non linear crystals for frequency doubling or tripling offering the possibility for most efficient two or three step ionization.

### 3.2 The ISOLDE Targets

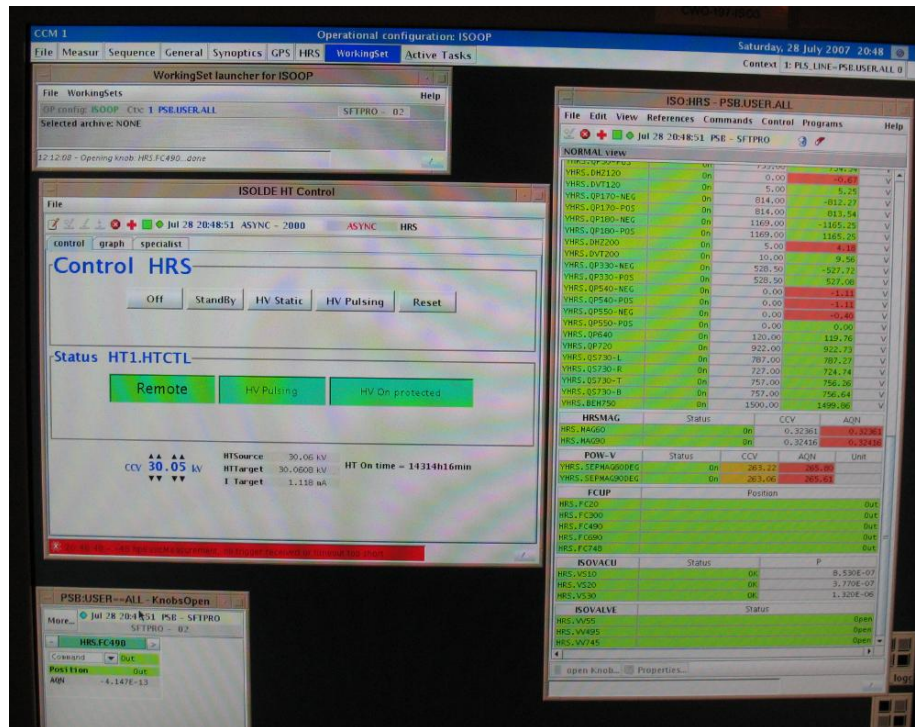


Figure 8: The HRS high voltage control while running at 30 KV pulsed.

In order to get a beam out of ISOLDE, we have to have the ISOLDE target under high voltage. Sometimes this trips and has to be reset using a control window like the one shown in figure 8. This one is for the HRS which is to be found on the consoles to the right as you come into the control room. There is a similar one for the GPS on the left-hand consoles. We normally run at 30 kV in pulsed mode. It can be reset after a trip by clicking “Reset” and then “HV Pulsing”

The target also has to be headed as does the transfer line. Both of these can trip as well, though this is often an indication that the target is about to fail. Changing the target heating has to be done **very** slowly.

### 3.3 The Separators

ISOLDE has two separators, the GPS and the HRS.

### 3.3.1 The General-purpose Separator (GPS)

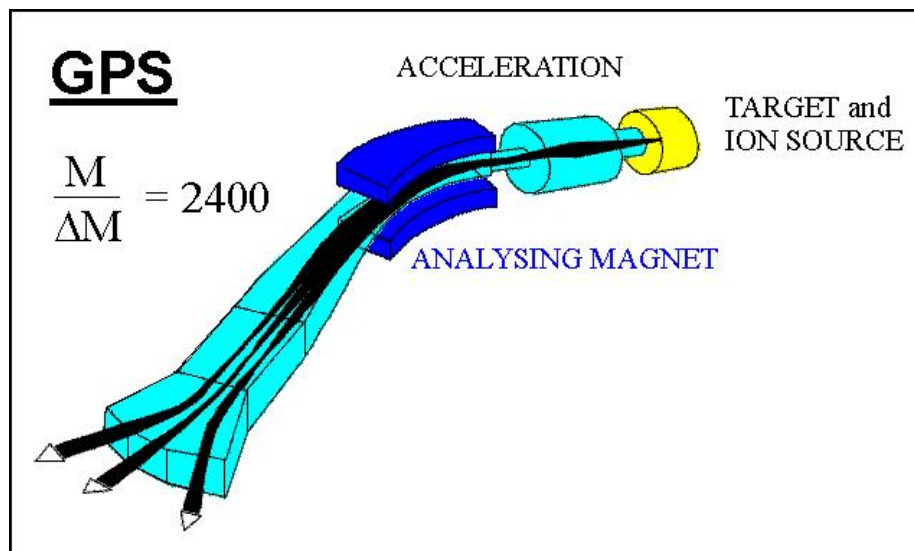


Figure 9: The general-purpose separator (GPS)

The General Purpose Separator (GPS) is designed to allow three beams, within a mass range of  $\pm 15\%$ , to be selected and delivered to the experimental hall. The magnet is double focussing H-magnet with a bending angle of  $70^\circ$  and a mean bending radius of 1.5 m. The mass resolving power is  $M/DM=2400$ .

### 3.3.2 The High-resolution Separator (HRS)

The second separator, the High Resolution Separator (HRS), is equipped with two bending C-magnets with bending angles  $90^\circ$  and  $60^\circ$  degrees, respectively. At the moment one single mass, with a resolution of about  $M/DM=5.000$ , can be separated routinely with the HRS separator.

## 3.4 ISCOOL

There is a helium-filled radio frequency quadrupole cooler and buncher on the HRS beam line just before the point, where this beam line joins the common beam line. It was intended as a replacement for REXTRAP and to be particularly useful for the now defunct NICOLE experiment. It should improve the beam properties for the low-energy beam, but this is largely irrelevant for HIE-ISOLDE. In fact, for most experiments, it just reduces the transmission, but we have to live with that.

## 3.5 ISOLDE beam and signals

The ISOLDE setup is typically set somewhere between 30 and 60 kVolts, so that is the extraction energy of the beam. For HIE-ISOLDE operation, where

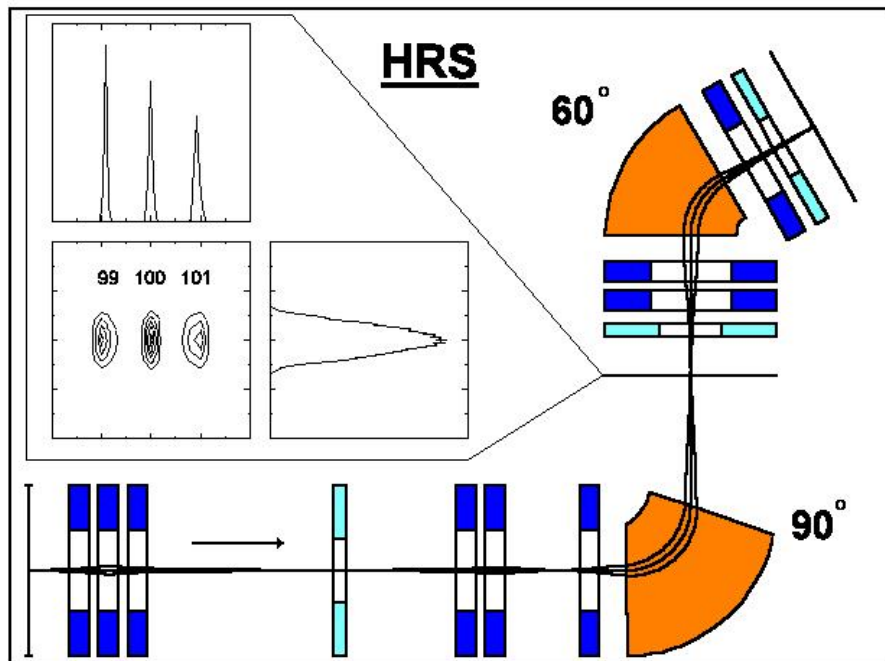


Figure 10: The high-resolution separator (HRS)

we want to trap this beam in REXTRAP, the low end of this range is used. i.e. 30 kV in pulsed mode.

The four rings of the PS booster facility deliver protons at 1.4 GeV in a supercycle lasting 14.4 seconds. During this time, 12 pulses are delivered, each containing 4 bunches of particles. The length of a pulse is  $1.25 \mu\text{s}$  and they are 1.2 seconds apart. The bunches are 230 ns with a gap of 120 ns.

We get several signals from ISOLDE. These are sent to a patch panel in rack RA02 of the ISOLDE control room (on the left as you enter). This patch panel is marked "Physics network links with control room" and it has several columns of BNC connectors with five connectors per column, each of which goes to a different patch panel. The patch panel for the Miniball platform is P13 which is the rightmost column of connectors. On the Miniball platform, the other end of these connections is labelled "Links to control room RA02" and is in the patch panel on the wall marked P13.

See EDMS <https://edms.cern.ch/document/2488071/1> for the full documentation of the ISOLDE timing system.

- PS (proton supercycle) - when the PS booster has its supercycle start. A supercycle typically lasts of the order of ten seconds or so and there is about one beam macropulse per second during that time. However, the pulses are used by several experiments, so we typically only get a couple

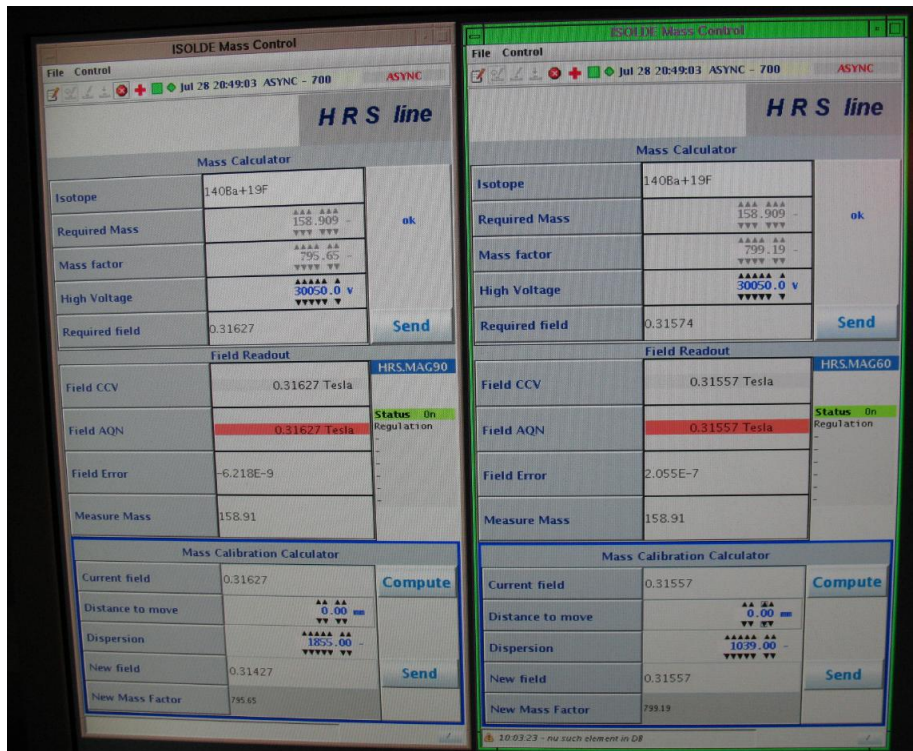


Figure 11: The high-resolution separator mass control display

of pulses. e.g. 5 pulses out of 12 in a 14.4 second supercycle. The PS signal comes at the beginning of each supercycle. This signal is available a module in the minirate around head-height in rack RA02 in the control room and is fed from there to the patch panel in the same rack, which is connected to the one on the Miniball platform.

- T1 - this pulse is a warning that the protons are about to hit the ISOLDE target (this is for each micropulse). This signal comes from the top module in rack RA02 of the ISOLDE control room but the connector is *at the back*. Note that there are two T1 pulses, depending on the separator, so make sure you have *T1 GPS* if you are using the general purpose separator and *T1 HRS* if you are using the high resolution separator.
- T2 - this is when the extraction gate is opened. There is a delay between T1 and T2 which is set in the control room. Usually this is not changed during an experiment, unless optimisation is taking place, so we don't usually acquire both T1 and T2 simultaneously. This signal comes from the second module from the top in rack RA02 in the ISOLDE control room. Like the signal for T1, there are separate signals for T2 GPS and T2 HRS and they are at the back of the module.
- laser status - this signal is part of the Leuven switching system for the laser on/off operation. It indicates whether the laser shutter is open or closed and consequently comes from the laser cabin, via a patch panel to

the patch panel in rack RA02 of the control room. From there it is patched to patch panel P13 on the miniball platform, which is also available from RA02.

- laser power - this is the power output of the laser, so again it comes from the laser cabin via a patch panel to the one in RA02 of the control room and from there to P13 on the Miniball platform.

### 3.5.1 Beam request

There are two beam request buttons one for HRS and one for GPS. These turn on and off the request for the proton beam. They are located on a single module in the minirate in rack RA02 in the control room (around head height). Above that rack, there are two large lights indicating whether the proton request is on or off for HRS and GPS.

### 3.5.2 Beam gate timing

The timing of the beam gate (T2) relative to the proton pulse (T1) is set by the electronics in rack RA10 of the control room.

## 4 The REXTRAP Penning Trap

In order to post-accelerate the radioactive isotopes, we first trap them in a Penning trap called REXTRAP. Here the ions are slowed down by collisions with a buffer gas (typically argon or neon). The potential in the trap is a well with one side just low enough for the 30 keV beam to enter, and the other side higher. Once the 30 keV beam enters the trap, it loses energy through collisions with the buffer gas and no longer has enough energy to get out of the trap. At some time, we lower the potential on the outgoing side and let the ions out.

## 5 The REXEBIS Electron-beam Ion Source

After extraction from the REXTRAP, the ions enter an electron beam ion source (REXEBIS). Here an electron gun is used to produce a beam of electrons which bombard the ions. These ions start in the  $1^+$  state coming out of the EBIS and are ionised through collisions between the electron beam and the electrons of the ions, which are then kicked out. The ionisation states obtained depend on the time the ions are in the trap (charge breeding time). Longer times result in higher charge states, but if the lifetime of the isotope is short, this may be a limiting factor.

The REXEBIS has attained a current density of  $150 \text{ A/cm}^2$  and beam currents of  $< 0.4 \text{ A}$ . A 1.5 m solenoid provides a trap length of 0.8 m with a magnetic field strength of 2 T. The electron beam energy is adjustable between



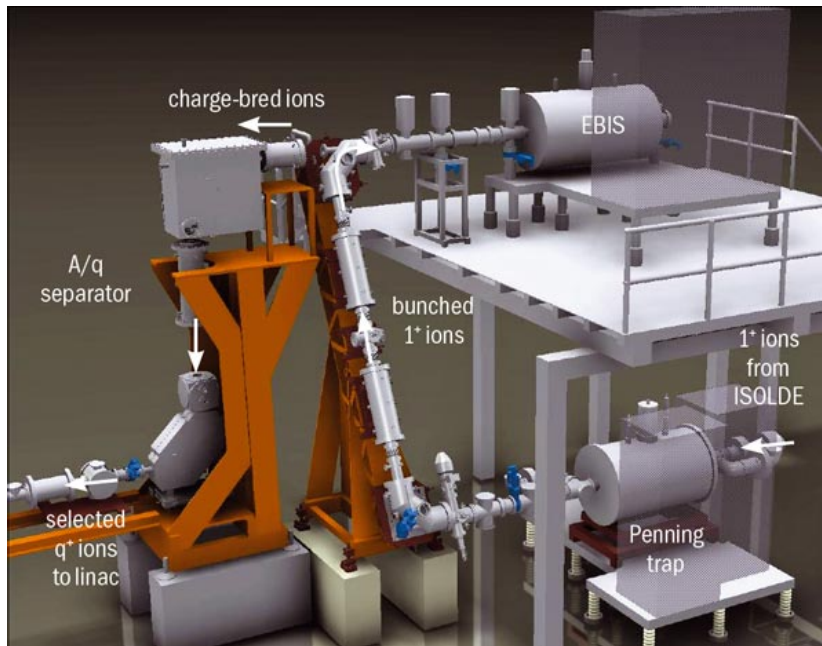


Figure 12: REXTRAP, REXEBIS and the separator. The beam comes in from right to left at the bottom, enters the Penning trap (REXTRAP) is them passed up to the EBIS (REXEBIS), charge bred, and then passes back down through the A/q separator

3 and 6 kV. For these parameters Na and K are charge bred to  $8+$  and  $15+$ , respectively, in 20 ms. To obtain a high breeding efficiency, the phase space overlap of injected ions and the electron beam has to be large. Hence, a rather low extraction emittance of  $<10 \pi$  mm mrad (95% at 60kV) from the Penning trap is required for a successful injection into the EBIS. Since only one specific charge state from the total charge state distribution coming out of the EBIS is selected in the successive mass separator, the maximum breeding efficiency is about 30%. The space charge from the electron beam determines an upper limit for the maximum number of positive ions that can be stored in each pulse, for the above parameters this gives  $5 \cdot 10^{10}$  charges. Assuming 50% neutralization,  $3 \cdot 10^9$  number of  $\text{Na}^+$  can be charge bred to  $\text{Na}^{8+}$  per pulse. This is almost one order of magnitude larger than the ion number which can be accumulated in the Penning trap.

The EBIS is located vertically above the REXTRAP.

You can check the beam going into the EBIS by putting in the injection plate and reading the value. However, make sure you actually hear it go in and out, because it sometimes sticks.

You can also click on the “read all” button at the top of the EBIS console (The computer on the far right in the control room) to read all the values to check that nothing has tripped).

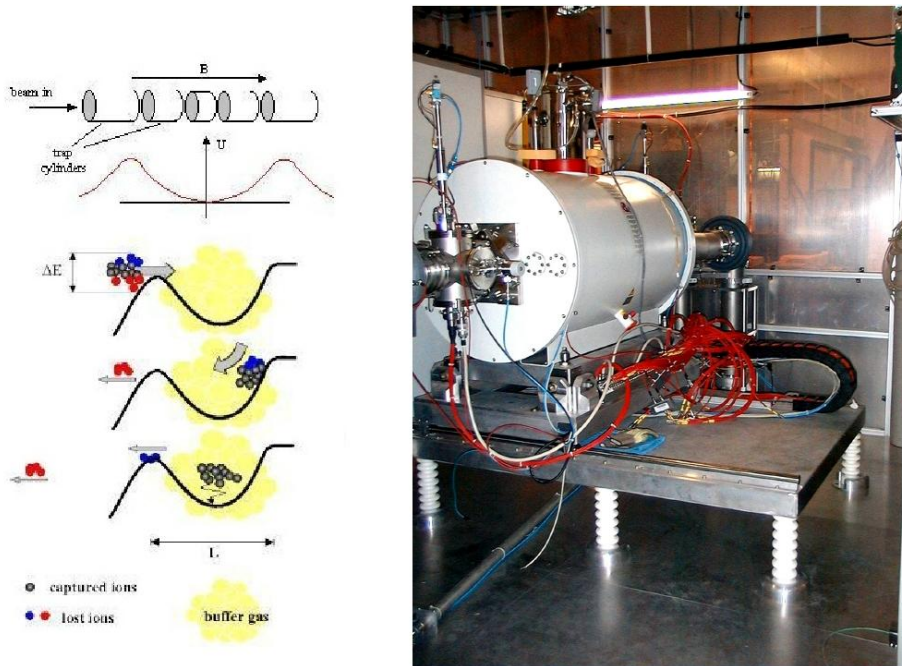


Figure 13: REXTRAP

## 6 The Mass Separator

The ISOLDE separators (HRS, GPS) perform an accurate separation by mass on the  $1^+$  beam, which combined with element-sensitive ionisation (e.g. the RILIS) gives quite good selection of a particular isotope. However, at the exit from the EBIS, there are also other components in the beam such as the residual gases which are left despite pumping to high vacuum. The main contaminants are:  $^{14}\text{N}$ ,  $^{15}\text{N}$ ,  $^{16}\text{O}$ ,  $^{18}\text{O}$ ,  $^{20}\text{Ne}$ ,  $^{22}\text{Ne}$ ,  $^{12}\text{C}$ ,  $^{13}\text{C}$ ,  $^{36}\text{Ar}$ ,  $^{40}\text{Ar}$ . Furthermore, we have a variety of charge states. So after the EBIS, we have a mass separator which performs an  $A/q$  separation with  $\Delta(q/a) / (q/A)$  of 1/150.

The separator is built with two magnets, one bending the beam downwards (since the EBIS is up on a platform) and the other bending the beam back to the horizontal at the level of the beam line.

## 7 The Normal-Conducting REX Linac

The REX linac consists of six accelerating elements:

- A radio-frequency quadrupole (RFQ) to accelerate from 5 keV/u to 300 keV/u.



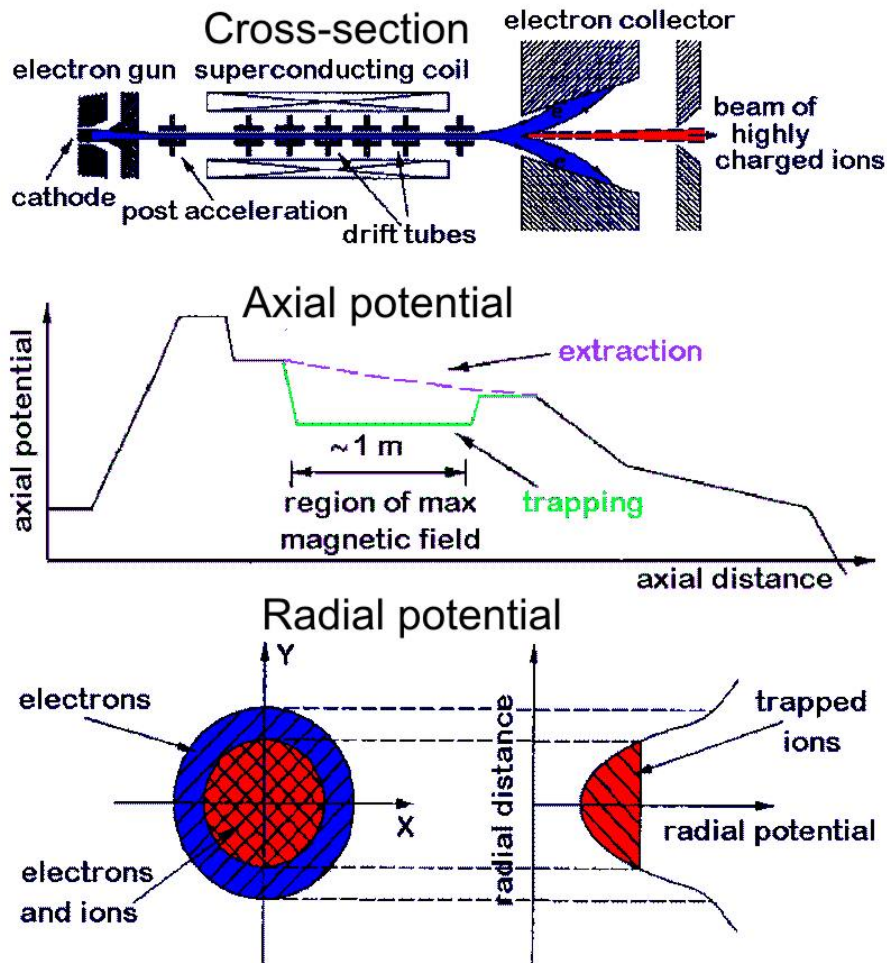


Figure 14: REXEBIS

- An interdigital H structure (IHS) to accelerate up to about 1.1-1.2 MeV/u.
- Three seven-gap resonators (7GAP) to accelerate to 2.2 MeV/u.
- A nine-gap resonator (9GAP) to accelerate to 3.0 MeV/u.

There is also a buncher between the RFQ and the IHS.

All of these elements operate at 101.28 MHz, except for the 9-gap resonator which works at exactly twice this frequency. The amplifiers for these radiofrequency devices in the amplifier room on the first floor (not far from the EBIS platform).

Note, that there are several limits which come into play.

- The maximum charge state is limited by the charge breeding time vs. the half life of the isotope. For very short lived isotopes, increasing the breed-

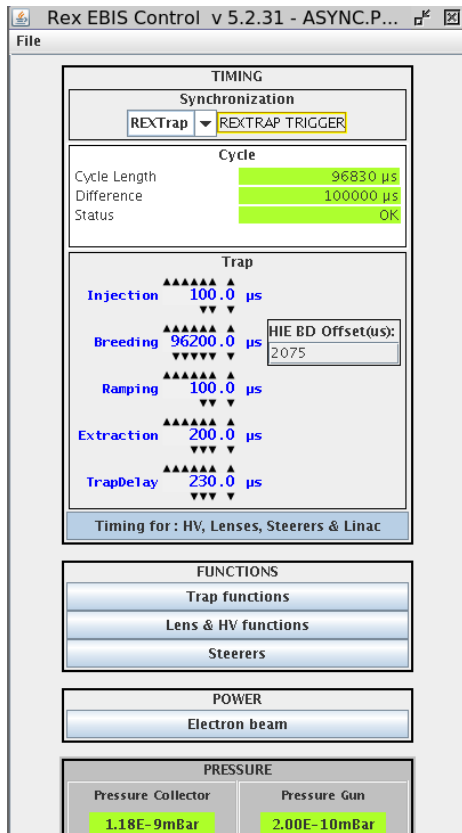


Figure 15: EBIS control panel. The “difference” is the period of the EBIS cycle (here 100000  $\mu\text{s}$  i.e. 10 Hz).

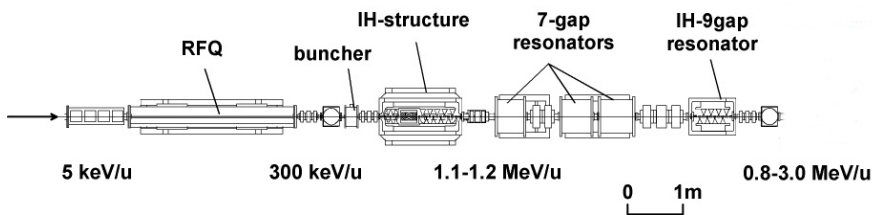


Figure 16: The normal-conducting REX Linac, showing the acceleration from 5 keV/u up to a maximum of 3 MeV/u. These values are for a beam with  $A/q = 4.5$ . After this, it can enter the superconducting part.

ing time, increases the fraction in the higher charge state, but decreases the absolute number, because of the decay.

- The maximum energy per nucleon obtainable for a given charge state is limited by the maximum power of the RF amplifier. In the past it was not possible to run the RF amplifier of the 9 gap at full power, which limited the maximum to around 2.85 MeV/u, rather than the 3 MeV/u by design.

- In the past, the bending magnet after REX imposed a limit on the maximum beam energy for a given charge state. This limitation should no longer be relevant for HIE-ISOLDE.

## 7.1 REX beamline elements

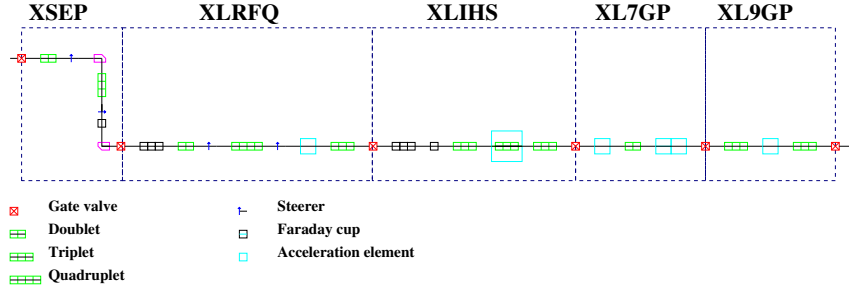


Figure 17: REX beamline elements

The REX beamline is divided into six sections with valves between each section:

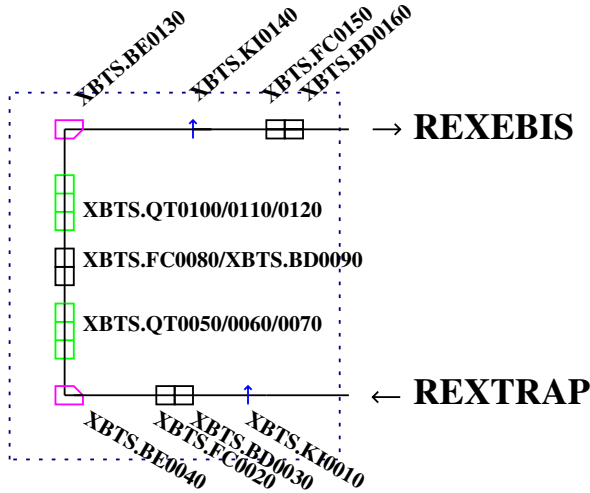
- XBTS - the beam transfer section between the trap and the EBIS
- XSEP - the separator area (between V1 and V2)
- XLRFQ - the radio-frequency quadrupole area (between V2 and V3)
- XLIHS - the interdigital H structure area (between V3 and V4)
- XL7GP - the 9-gap resonators area (between V4 and V5)
- XL9GP - the 7-gap resonators area (between V5 and V6)

### 7.1.1 The XBTS area

The elements are as follows:

Element Name	Meaning
XBTS.KI0010	Electrostatic kicker
XBTS.FC0020	Faraday cup
XBTS.BD0030	Beam diagnostics
XBTS.BE0040	Electrostatic bender
XBTS.QT0050/0060/0070	Quadrupole triplet
XBTS.FC0080	Faraday cup
XBTS.BD0090	Beam diagnostics
XBTS.QT0100/0110/0120	Quadrupole triplet
XBTS.BE0130	Electrostatic bender
XBTS.KI0140	Electrostatic kicker
XBTS.FC0150	Faraday cup
XBTS.BD0160	Beam diagnostics

# BTS







-  **Triplet**
-  **Beam diagnostics**
-  **Kicker**
-  **Electrostatic bender**

Figure 18: REX beam transfer section from REXTRAP to REXEBIS

## 7.1.2 The XSEP area

The elements are as follows:

Element Name	Meaning
V1	Gate valve
XSEP.ZQP.0100/0200	Electrostatic octupole doublet
XSEP.ZQS.0200	Electrostatic steerer
XSEP.ZBE.0300	Electrostatic bender of separator
XSEP.ZQP.0400/0500/0600	Electrostatic quadrupole
XSEP.ZQS.0600	Electrostatic steerer
XSEP.BFC.0800	Faraday cup (aka. XSEP.FC80)
XSEP.BBO.0900	Beam observation
XSEP.MB.1000	Magnetic dipole bender of separator

Note that XSEP.BFC.0800 sees all the residual gas beam from the EBIS, even if there is no beam coming from ISOLDE. So seeing something at XSEP.BFC.0800 and not seeing anything at the next cup (XRFQ.BFC.0200) doesn't necessarily mean there is beam up to XSEP.BFC.0800. It could be that this cup is just seeing

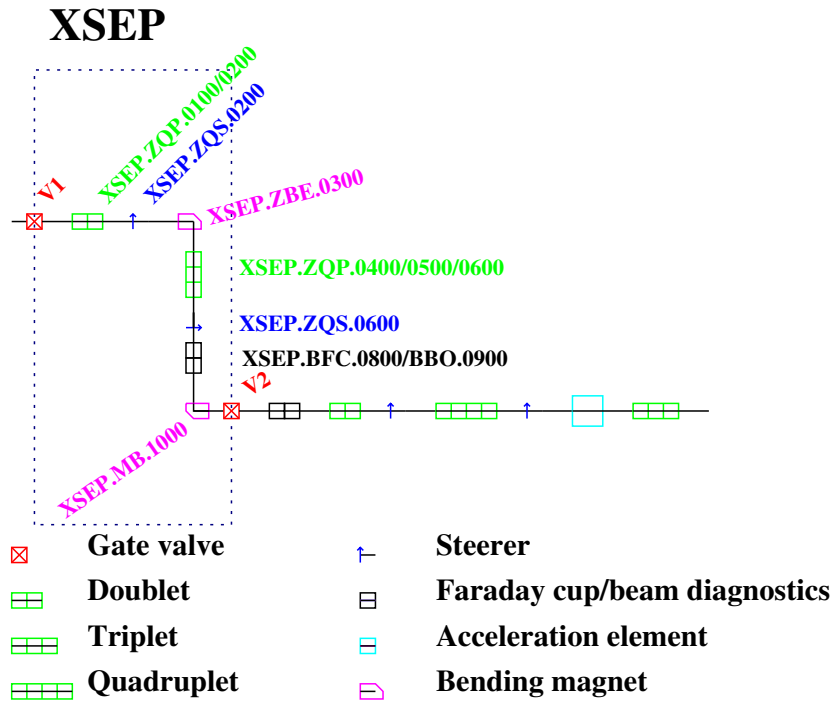


Figure 19: REX beamline elements in the separator area

the residual gas beam, which doesn't make it round the magnet XSEP.MB.1000.

### 7.1.3 The XLRFQ area

The elements are as follows:

Element Name	Meaning
V2	Gate valve
XLRFQ.BDB.0100	Beam diagnostic box
XLRFQ.BFC.0200	Faraday cup (aka. XRFQ.FC20)
XLRFQ.BBO.0300	Beam observation
XLRFQ.ZQP.0400	Electrostatic quadrupole
XLRFQ.ZQS.0500	Electrostatic steerer
XLRFQ.ZQP.0700/0800/0900	Electrostatic quadrupole triplet
XLRFQ.ZQS.1000	Electostatic quadrupole steerer
XLRFQ.ARFQ.1150	The RF quadrupole acceleration element
XLRFQ.MQ.1100/1200/1300	Magnetic quadrupole triplet

Note that up to the RFQ itself, the focusing and steering is electric, but after, the focusing and steering has to be magnetic.

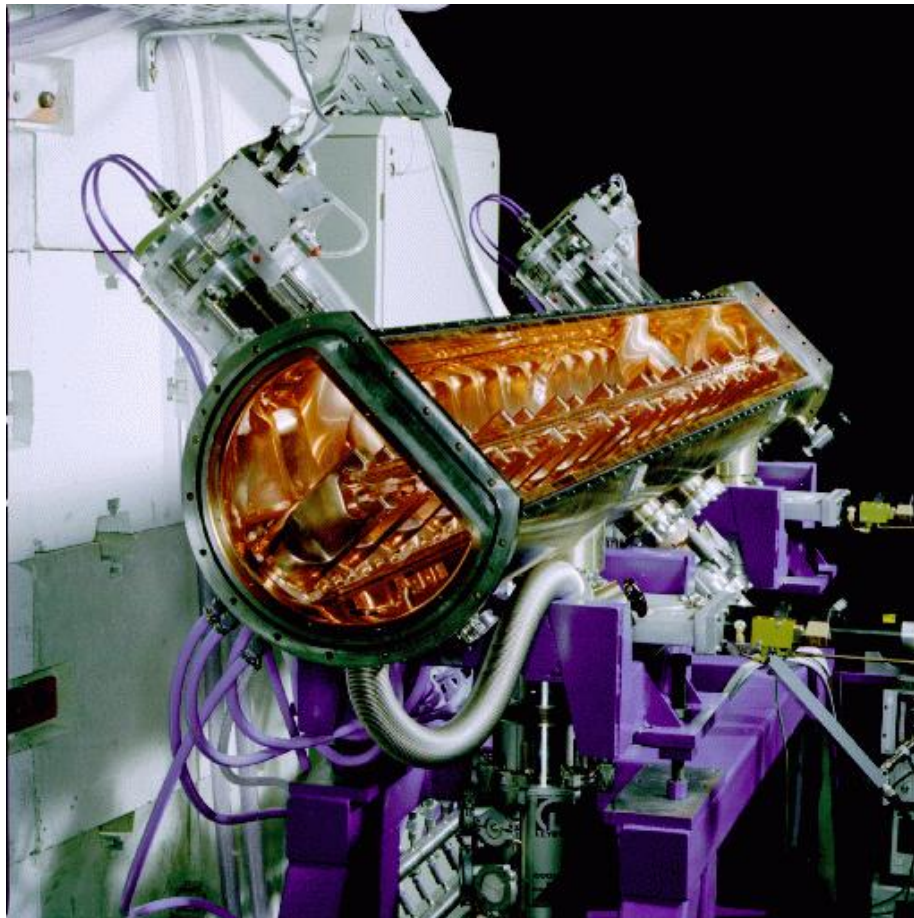


Figure 20: The RFQ

## 7.2 The REX amplifiers

The acceleration units at REX are radio-frequency cavities, where a high frequency oscillation is sent between electrodes, synchronized with the passage of the bunch of beam particles, so that they always see an accelerating potential. To achieve this, high-power radio-frequency amplifiers are needed to produce the necessary RF. These are located in a room on the floor above REX, accessible from the same platform that goes to the EBIS.

Each amplifier has two racks. The leftmost is for the control and generation of the RF.

This rack has a panel of lights at the top. Normally only one green light in the bottom right hand corner of the panel lights up, but if an error occurs, one or more red lights come on and the two yellow buttons above the green light light up. Pressing these buttons (the upper one first) resets the error condition.

Below the lights is a Siemens simatic control system. It has lots of lights and

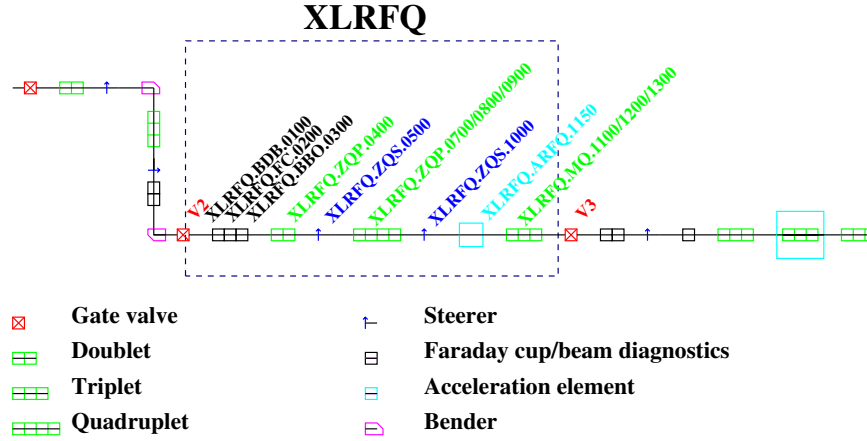


Figure 21: REX beamline elements in the RFQ area

controls the logic, but there is nothing that can be done with it.

Under that are gauges indicating the power.

Below that is the control unit. In normal operation the “Lev1” and “Lev2” lights should be on and the  $P_F$  final (“forward” power) should be indicating tens of kilowatts, while the  $P_R$  final (“reverse” or “reflected” power) should be zero. The “Lev1” and “Lev2” buttons are used to switch on the system, first to level one by pressing “Lev1” and then to level 2 by pressing the other button.

Underneath that are the filament, grid1, anode, grid2 and preamp units. They should all be “ON” in normal operation. There is normally no reason to touch anything on any of these units, since the turning on is done via the “Lev1” and “Lev2” buttons on the control unit.

The second rack is for the tuning.

At the top is another Siemens simatic control unit, which has many lights but nothing to control.

Under it is the tuning control. There are three modes set by a knob on the top left of this section:

- remote - the system is controlled by the computers from windows in the control room, via the simatic.
- local - the system is controlled from this panel in the amplifier room.
- open loop - also controlled from this panel.

Under that knob is the open-loop gain potentiometer which sets the amplitude. On the same panel there is a tuning select knob (automatic or manual) and





Figure 22: REX amplifier for the 3<sup>rd</sup> 7-gap resonator, showing the two racks (each cut in two by the photograph).

tuning in and out buttons for manual mode. There is also a green “Tuning OK” light, which lights up when it is in tune. Finally, there is a display which the simatic uses to display messages, though these are not always helpful as it sometimes displays very old messages.

Below that, there is an oscilloscope showing the tuning signals and under that the tuning electronics. This electronics receives a signal from a pickup in the

cavity and uses it to determine the amplitude of the signal, so as to tune the phase of the RF.

### 7.2.1 Amplifier trips

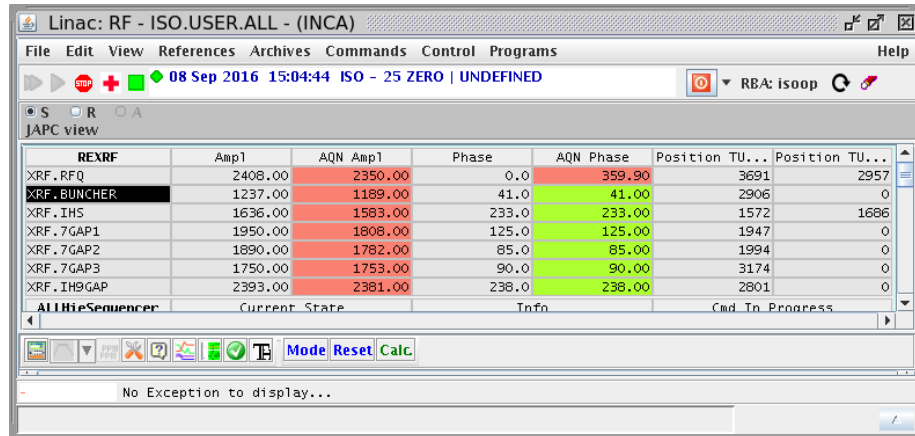


Figure 23: RF control panel. The “AQN Amp1” column tells us if the amplifier is running. If this shows zero (or almost zero), it has tripped. Note that there are other versions of this display, but they show the same numbers.

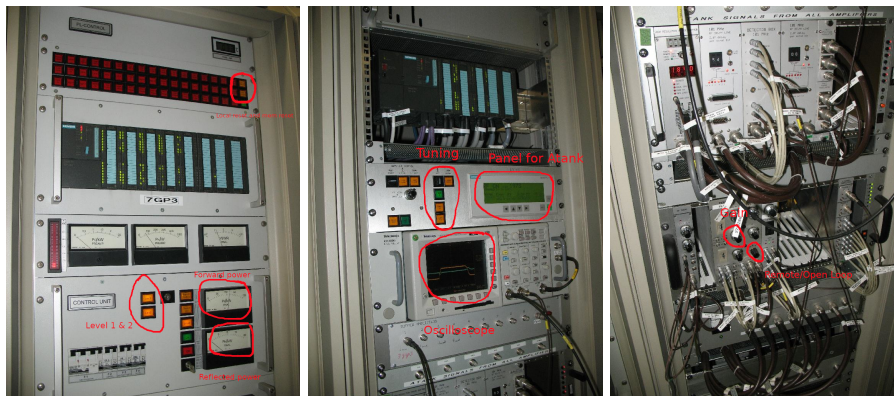


Figure 24: RF amplifier of the third 7-gap. The others are similar, but the IHS has two tuners and the preamplifier of the 9-gap is at the top.

Often the REX amplifiers trip. Most frequently this is due to too much reflected power, but not always. When a trip occurs, the system shuts down and one or more red lights appear on the panel of lights at the top of the left rack (top right for the 9-gap) labelled “PL Control”. Look at the RF control panel (see fig. 23) to see if an amplifier has tripped and which one, or if you are in the amplifier room, you can see the red lights. To restart follow the following procedure:

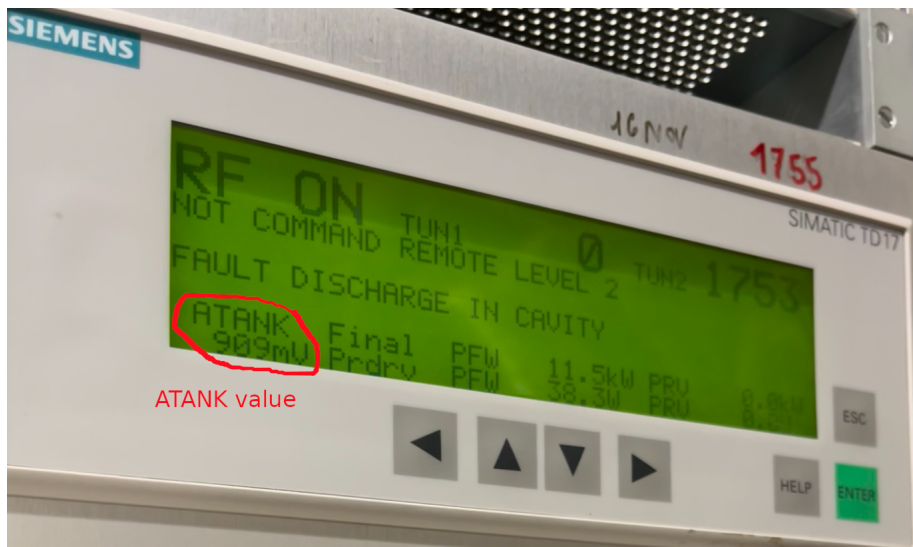


Figure 25: The Siemens Simatic display panel showing the ATANK value. Note that the “Fault discharge in cavity” is normal. This is the error that caused the RF to trip in the first place. This one is from the IHS, where we use TUN2.

- Write down in the HIE-ISOLDE log book which amplifier tripped and which lights were lit on the panel top left (top right for the 9-gap) in the PL control unit.
- Turn the open loop gain knob on the feedback control NIM module to zero (labelled “A”) . Do **not** touch the the other knobs like “Maximum A”, “Initial A”, “PH” or “Loc. A Ref.”. Do **not** touch the other modules like “Tuning control” or “Local timing”.
- Turn the control mode from remote (“REM”) to open loop (“OPEN L”). This is a three position switch knob. This means that it will stop using the reference sent from the control room, but use the open loop reference, which was just turned down to zero in the previous step.
- Press the two yellow buttons (local reset and mem reset) on the light panel at the top of the left rack (top right for the 9-gap) in the PL control unit. They should be lit and should go off, when you press and then only the green light should be on in that panel. If not, press the “Faults reset” button on the second rack.
- If the “Lev1” button is not lit, press it and wait for it to come on. This takes a while, as the control unit has to power some things up. It can also make loud clicks.
- Press the “Lev2” button. This causes the control unit to switch everything else on. Again it might take a moment, depending on the state the system was in. It might also make loud clicks.
- Once the “Lev2” button is lit, slowly increase the open-loop gain. At first nothing happens. At some point, the  $P_F$  final gauge on the control unit

should start rising (this is the one we want to have power). The  $P_R$  final one will probably start twitching (this is the one we don't want) and a signal should appear on the oscilloscope (forward = yellow, reflected = blue). Also the tuning in and out lights might blink from time to time, and the "Tuning OK" light might light up occasionally. Continue slowly increasing, but don't let the  $P_R$  final go above 5 kW. Normally, once there is enough power, the tuning should kick in and tune so that the  $P_R$  final goes right down to zero and the "Tuning OK" light comes on. Once this happens, you can turn up a bit faster (but not too fast). For the 9-gap and IHS, the tuning probably won't kick in, when you get reflected power, so you have to switch the tuning to manual<sup>1</sup> and then use the tuner in/out buttons (tuner 2 for the IHS) to get rid of the reflected power (until the "Tuning OK" light comes on) and then go back to automatic. For the 9-gap, if it starts getting jittery, lower the gain a little, wait a bit and then increase again. Increase until the Siemens Simatic LCD display panel shows that "ATANK" has reached the correct value (see figure 25. If you don't know what this is, you can use the left and right arrow buttons on that Siemens Simatic LCD display to go through the pages. Somewhere there is a value for "Aref". That is what you want ATANK to go to.

- Switch from open loop back to remote mode. At this point we are switching the reference value from the setting of the open loop knob to that sent from the control room. As they should be about the same, this shouldn't make much difference.

### 7.2.2 The IHS area

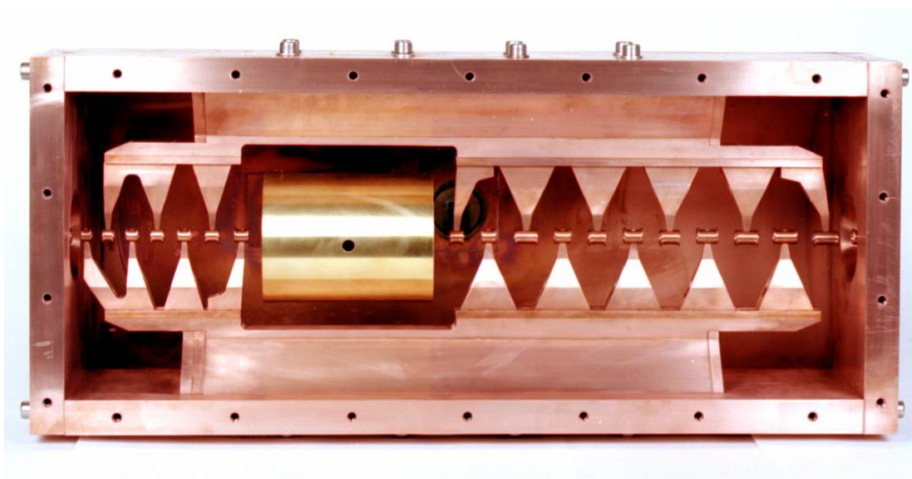


Figure 26: The interdigital H structure

<sup>1</sup>The tuning controls are next to the Siemens Simatic LCD display panel where you read Atank. There's a two-position knob to select auto or manual, the green "Tuning OK" light and yellow tuner in and out buttons. The IHS has two tuners, the others have one. Usually, you have to move the tuner in at first and then switch to automatic and it will move it back out as you increase the gain.



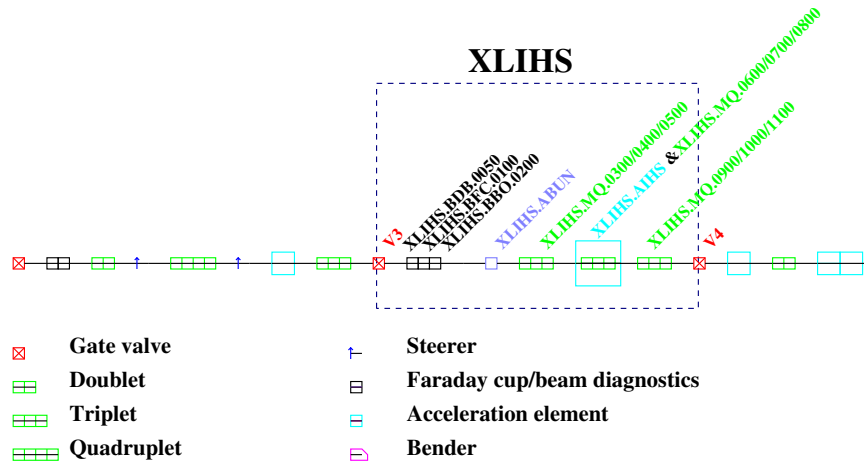


Figure 27: REX beamline elements in the IHS area

The elements are as follows:

Element Name	Meaning
V3	Gate valve
XLIHS.BDB.0050	Beam diagnostic box
XLIHS.BFC.0100	Faraday cup (aka. XIHS.FC10)
XLIHS.BBO.0200	Beam observation
XLIHS.ABUN.0250	Buncher
XLIHS.MQ.0300/0400/0500	Magnetic quadrupole triplet
XLIHS.AIHS.0550	The IHS acceleration element
XLIHS.MQ.0600/0700/0800	Magnetic quadrupole triplet (inside IHS)
XLIHS.MQ.0900/1000/1100	magnetic quadrupole triplet

### 7.2.3 The 7GP area

The elements are as follows:

Element Name	Meaning
V4	Gate valve
XL7GP.A7GP.0100	First 7-gap resonator
XL7GP.MQ.0110/0120	Magnetic quadrupole doublet
XL7GP.A7GP.0200	Second 7-gap resonator
XL7GP.A7GP.0300	Third 7-gap resonator

### 7.2.4 The 9GP area

The elements are as follows:



Figure 28: A 7-gap resonator

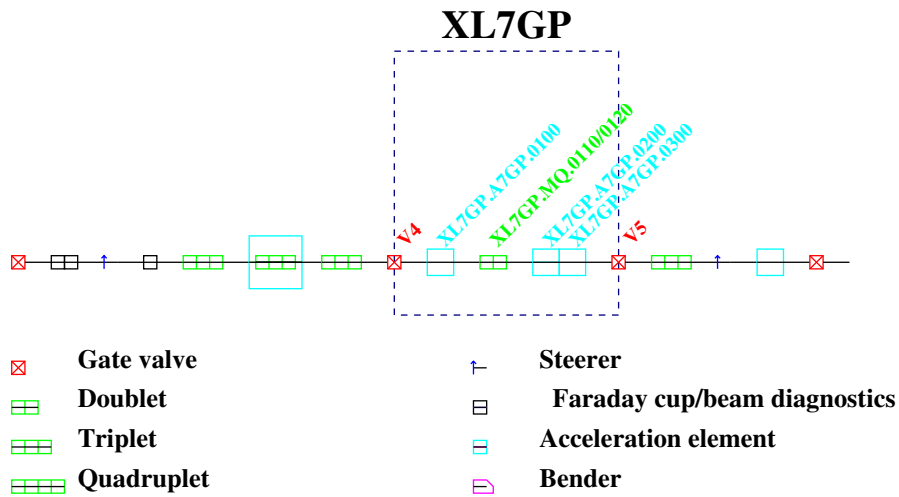


Figure 29: REX beamline elements in the 7-gap area

Element Name	Meaning
V5	Gate valve
XL9GP.MQ.0100/0200/0300	Magnetic quadrupole triplet
XL9GP.MC.0400	Magnetic steerer
XL9GP.A9GP.0500	9-gap resonator
XL9GP.MQ.0600/0700/0800	Magnetic quadrupole triplet

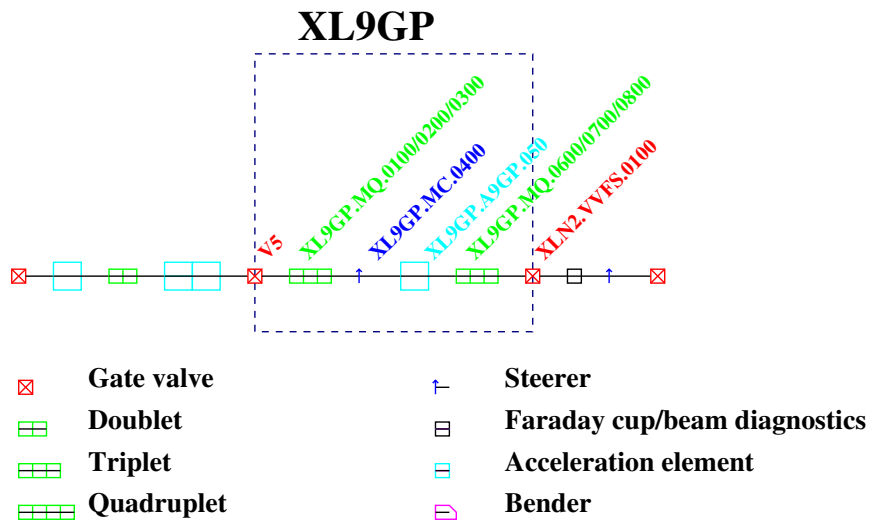


Figure 30: REX beamline elements in the 9-gap area

### 7.3 Beam diagnostics

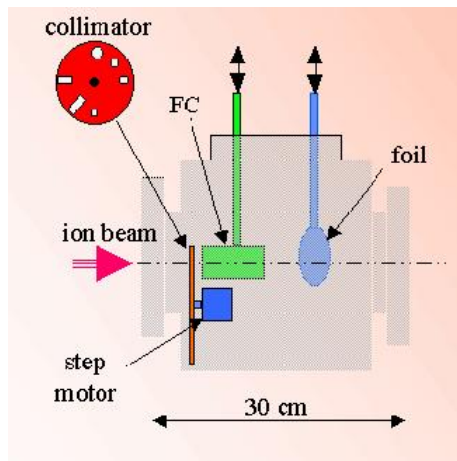


Figure 31: The old Leuven diagnostic box - HIE-ISOLDE is now using new diagnostic boxes

The various faraday cups are housed within the new short diagnostic boxes. These are only 120 mm long in the direction of the beam, as they have to fit in a rather tight space, constrained by the beam optics. However, they have



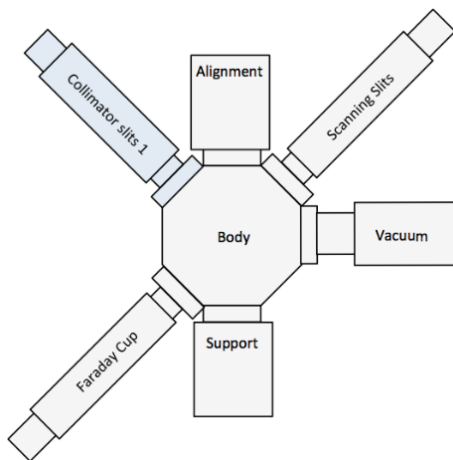


Figure 32: The new diagnostic box, which is just 120 mm deep.

three actuators, which stick out a long way perpendicular to the beam direction.

The short diagnostic box has collimator slits on one actuator, scanning slits on another and a Faraday cup on the third. In fact, there are four different designs. The one shown in fig. 32 is the first type. The second one has also a stripping foil on a fourth diagonal actuator, while the third has a silicon detector on a horizontal actuator and the fourth has both the stripping foil and the silicon detector.

### 7.3.1 Restarting the beam diagnostics

This section may well be obsolete, as I think they have completely redone the beam diagnostics system!

Sometimes the computer program controlling the cups crashes. This computer is located at the old entrance to the ISOLDE building. It is the third rack along and the computer is labelled “FEC Beam diagnostics”. The user name is rexdev and the password is the same as the REX password (at least it was in September 2007). Two programs have to run on this computer. One is the “Front End Computer Main” program (FECMain) and the other is the “RPC gateway”. The former is a windows application, the latter is MS-DOS.

If the cup control crashes, the status goes from being either “IN” or “OUT” to “UND” (in red) and stays that way (note that it may be briefly “UND” when putting a cup in or out, but when the system crashes it stays that way. The error window on the REX console usually gives “communication error” messages for each faraday cup and beam diagnostics box.

In this case, use the windows task manager to kill FECMain and also kill RPC-Gateway. Then restart FECMain (it should end up with the message “Initialisation completed successfully”). Then start RPCGateway. Both of these programs have icons.

It should then be possible to control the cups from the control room.

## 8 The superconducting LINAC

### 8.1 The cryomodules

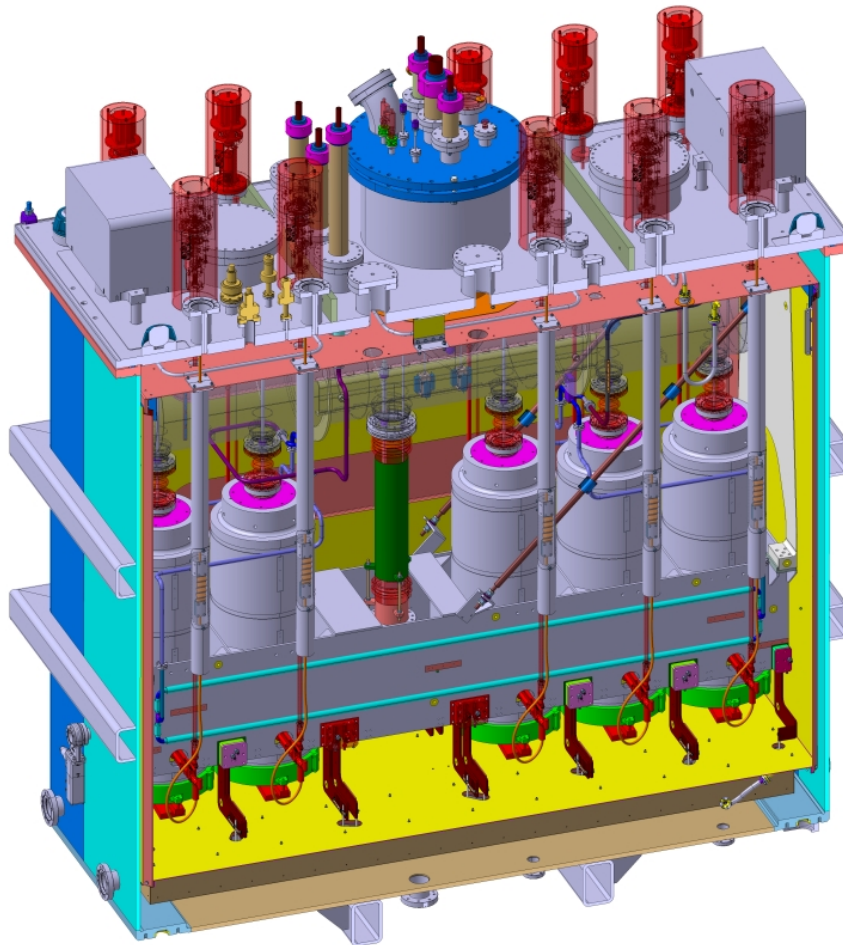


Figure 33: The design of the high- $\beta$  cryomodule. The beam goes from left to right. First there is a vacuum valve outside the cryogenic housing, then two cavities, a solenoid, then three more cavities inside.

The  $\approx 3$  MeV/u beam from the 9-gap is then accelerated further using the superconducting-LINAC part. This consists of superconducting cryomodules. These have Nb/Ti superconducting solenoids surrounded by an iron yoke, enclosed in a stainless steel vessel filled with liquid helium at 4.5 K. Each solenoid

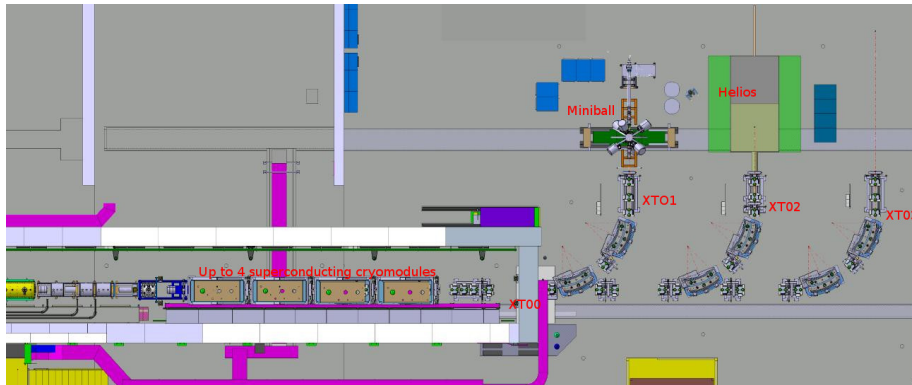


Figure 34: The planned HIE-ISOLDE beamlines showing four cryomodules. The beam goes from left to right. After the common section XT00, there are three possible bending points to the XT01, XT02 and XT03 lines.

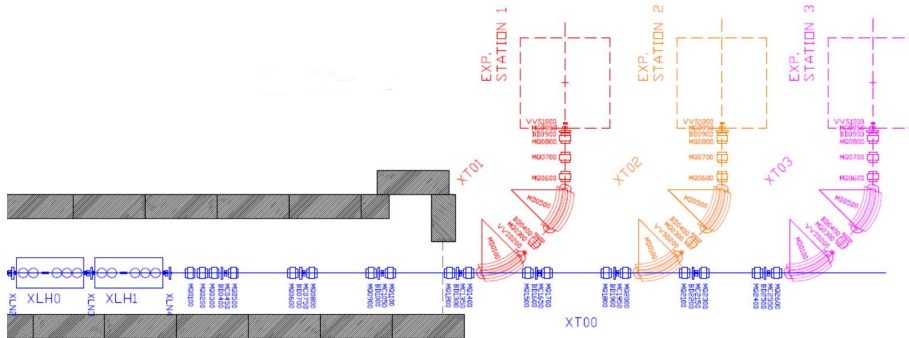


Figure 35: The superconducting LINAC and XT beamlines. At the left are the two cryomodules separated by the XLN2, XLN3 and XLN4 sections (in blue). XT00 is also shown in blue, XT01 in red, XT02 in orange and XT03 in purple.

is 31.2 cm long and works with a nominal current of 115.5 A. In order to synchronise with REX, they have to operate also at 101.28 MHz.

As the position of the solenoids has to be within 0.15 mm, their position is constantly monitored using a system based on CCD cameras.

Sometimes a cavity trips. In this case, it is necessary to go to the panel shown in figure 36. The one which has tripped will show “Standby”. In this case, you just have to click on “On” and an automatic procedure is started to ramp it back up. This takes some time, but it shows messages under “Detailed status” about what it is doing.

There will be two kinds of cryomodule:

- low- $\beta$  ( $\beta_0 = 6.3 \%$ ) each with 5 cavities



Figure 36: The control panel for the cryomodules. Here XLL2.CAV3, XLH1.CAV4 and XLH1.CAV5 are switched off.

- high- $\beta$  ( $\beta_0 = 10.3\%$ ) each with 6 cavities

The high- $\beta$  ones will be put in first. Eventually, the low- $\beta$  ones will be used instead of the old 7-gap and 9-gap resonators.

In the first stage (2015), only a single high- $\beta$  cryomodule with 5 cavities will be in use. This will yield 4.3 MeV/u for  $A/q = 4.5$ .

During the winter shutdown (2015/16) a second identical high  $\beta$  cryomodule will be added, taking the beam energy up to 5.5 MeV/u for  $A/q = 4.5$ . This is phase 1.

In phase 2, two further high- $\beta$  cryomodules of the same type will be added bringing the beam energy up to 10 MeV/u for  $A/q = 4.5$ . This is expected to be before the second long shutdown of CERN (2017).

In phase 3 the low-energy part of REX (7-gaps and 9-gap resonators) will be replaced by low- $\beta$  cryomodules, each with 6 cavities. This will give a total of 20 high- $\beta$  and 12 low- $\beta$  cavities and bring the beam energy to 10 MeV/u for  $A/q = 4.5$  or 20 MeV/u for  $A/q = 2$ . This is planned for 2019.

The superconducting LINAC beamline is divided into five sections with valves between each section:

- XLN2 - a diagnostics section
- XLH0 - the first cryomodule

- XLN3 - a diagnostics section
- XLH1 - the second cryomodule (not present in 2015)
- XLN4 - a diagnostics section

## 8.2 The XLN2 area

The elements are as follows:

Element Name	Meaning
XLN2.VVFS.0100	Fast vacuum valve
XLN2.BFC.0300	Faraday cup
XLN2.MC.0200	Magnetic steerer

## 8.3 The XLH0 area

This is the area of the first cryomodule. The vacuum valve at the entrance is just outside the cryomodule casing, but everything else seems to be inside. The elements are as follows:

Element Name	Meaning
XLH0.VVGS.0050	Vacuum valve
XLH0.QMH.0100	Cryogenics
XLH0.AQH.0200	First cavity
XLH0.AQH.0300	Second cavity
XLH0.ML.0400	Solenoid
XLH0.AQH.0500	Third cavity
XLH0.AQH.0600	Fourth cavity
XLH0.AQH.0700	Fifth cavity

## 8.4 The XLN3 area

The elements are as follows:

Element Name	Meaning
XLN3.VVGS.0100	Vacuum valve
XLN3.MC.0200	Magnetic steerer
XLN3.BFC.0300	Faraday cup

## 8.5 The XLH1 area

This is the area of the second cryomodule. The vacuum valve at the entrance is just outside the cryomodule casing, but everything else seems to be inside. Note that the second cryomodule is not present in 2015. The elements are as follows:

Element Name	Meaning
XLH1.VVGS.0050	Vacuum valve
XLH1.QMH.0100	Cryogenics
XLH1.AQH.0200	First cavity
XLH1.AQH.0300	Second cavity
XLH1.ML.0400	Solenoid
XLH1.AQH.0500	Third cavity
XLH1.AQH.0600	Fourth cavity
XLH1.AQH.0700	Fifth cavity

## 8.6 The XLN4 area

The elements are as follows:

Element Name	Meaning
XLN4.VVGS.0100	Vacuum valve
XLN4.MC.0200	Magnetic steerer
XLN4.BFC.0300	Faraday cup

## 8.7 The common beam line (XT00)

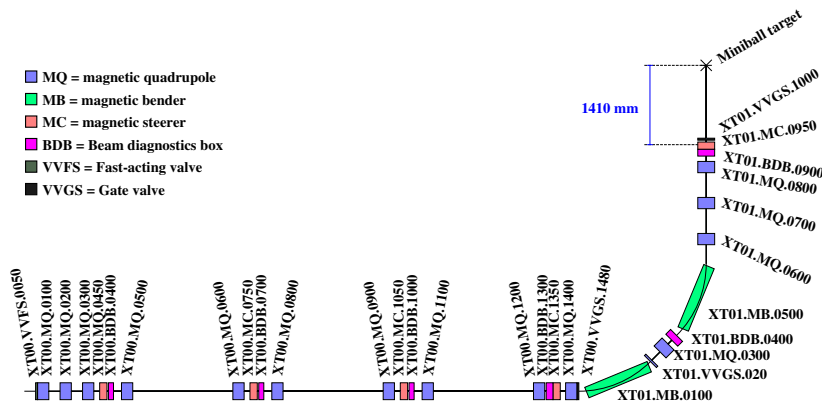


Figure 37: The XT00 and XT01 beam lines. The beam goes from bottom left to top right. This diagram is to scale. The distance from the centre of XT01.MC.0950 to the focus is 1410 mm. The horizontal part is XT00 and where it starts to curve towards the vertical is the start of XT01. The elements of XT00 going to the other beam lines are not shown.

The common beam line XT00 starts inside the tunnel and continues out past the points where the XT01 and XT02 beamlines are connected and through to the start of XT03. If the first dipole magnet of XT01 is off, the beam continues in a straight line and can be bent into XT02 or allowed to go on to be bent into XT03.

### 8.7.1 Inside the tunnel up to the start of XT01

This is the section inside the tunnel from the cryomodule(s) up to the start of the XT01 beamline. It is shown in blue in figure 35.

The elements are as follows:

Element Name	Meaning
XT00.VVFS.050	Fast vacuum valve
XT00.MQ.0100/200/300	Magnetic quadrupole triplet
XT00.MQ.0450	Magnetic steerer
XT00.BFC.0400	Faraday cup
XT00.MQ.0500	Magnetic quadrupole Drift region
XT00.MQ.0600	Magnetic quadrupole
XT00.MC.0750	Magnetic steerer
XT00.BFC.0700	Faraday cup
XT00.MQ.0800	Magnetic quadrupole Drift region
XT00.MQ.0900	Magnetic quadrupole
XT00.MC.1050	Magnetic steerer
XT00.BFC.1000	Faraday cup
XT00.MQ.1100	Magnetic quadrupole Drift region
XT00.MQ.1200	Magnetic quadrupole
XT00.BFC.1300	Faraday cup
XT00.MC.1350	Magnetic steerer
XT00.MQ.1400	Magnetic quadrupole
XT00.VVGS.1480	Vacuum valve Start of XT01

### 8.7.2 From XT01 to XT02

This is the section between the XT01 and XT02 beamlines. It is shown in blue in figure 35.

Element Name	Meaning
XT00.MQ.1500	Magnetic quadrupole
XT00.BDB.1600	Beam diagnostic box
XT00.MC.1650	Magnetic steerer
XT00.MQ.1700	Magnetic quadrupole Drift region
XT00.MQ.1800	Magnetic quadrupole
XT00.BDB.1900	Beam diagnostic box
XT00.MC.1950	Magnetic steerer
XT00.MQ.2000	Magnetic quadrupole Start of XT02



### 8.7.3 From XT02 to XT03

This is the section between the XT02 and XT03 beamlines. It is shown in blue in figure 35.

Element Name	Meaning
XT00.MQ.2100	Magnetic quadrupole
XT00.BDB.2200	Beam diagnostic box
XT00.MC.2150	Magnetic steerer
XT00.MQ.2300	Magnetic quadrupole
	Drift region
XT00.MQ.2400	Magnetic quadrupole
XT00.BDB.2500	Beam diagnostic box
XT00.MC.2550	Magnetic steerer
XT00.MQ.2600	Magnetic quadrupole
	Start of XT03

### 8.8 The Miniball beam line (XT01)

This is the section from XT00 to Miniball. It is shown in red in figure 35. The first five elements are in the bending section, where the beam is bent through  $90^\circ$ . The remaining six elements are in the straight section.

Element Name	Meaning
XT01.MB.0100	Magnetic dipole bender ( $45^\circ$ )
XT01.VVGS.0200	Vacuum valve
XT01.MQ.0300	Magnetic quadrupole
XT01.BDB.0400	Beam diagnostic box
XT01.MB.0500	Magnetic dipole bender ( $45^\circ$ )
XT01.MQ.0600/0700/0800	Magnetic quadrupole triplet
XT01.BDB.0900	Beam diagnostic box
XT01.MC.0950	Magnetic steerer
XT01.VVGS.1000	Vacuum valve

### 8.9 The second beam line (XT02)

This is the section from XT00 to the ISOLDE Solenoidal Spectrometer (ISS). It is shown in orange in figure 35. The first five elements are in the bending section, where the beam is bent through  $90^\circ$ . The remaining six elements are in the straight section.

Element Name	Meaning
XT02.MB.0100	Magnetic dipole bender (45°)
XT02.VVGS.0200	Vacuum valve
XT02.MQ.0300	Magnetic quadrupole
XT02.BDB.0400	Beam diagnostic box
XT02.MB.0500	Magnetic dipole bender (45°)
XT02.MQ.0600/600/800	Magnetic quadrupole triplet
XT02.BDB.0900	Beam diagnostic box
XT02.MC.0950	Magnetic steerer
XT02.VVGS.1000	Vacuum valve

### 8.10 The third beam line (XT03)

This is the section from XT00 to the place for additional experiments. It is shown in purple in figure 35. The first five elements are in the bending section, where the beam is bent through 90°. The remaining six elements are in the straight section.

Element Name	Meaning
XT03.MB.0100	Magnetic dipole bender (45°)
XT03.VVGS.0200	Vacuum valve
XT03.MQ.0300	Magnetic quadrupole
XT03.BDB.0400	Beam diagnostic box
XT03.MB.0500	Magnetic dipole bender (45°)
XT03.MQ.0600/700/800	Magnetic quadrupole triplet
XT03.BDB.0900	Beam diagnostic box
XT03.MC.0950	Magnetic steerer
XT03.VVGS.1000	Vacuum valve