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STATUS OF THE COMMISSIONING OF BEAM COOLER FOR SPES PROJECT

A. Ruzzon*, M. Maggiore, F. Gelain, D. Marcato, LNL-INFN, Legnaro, Italy
G. Ban, B. Bougard, J.F. Cam, P. Desrues, C. Gautier, J. Lory, Y. Merrer,
C. Pain, C. Vandamme, LPC, Caen, France

Abstract

A Beam Cooler (BC) device has been constructed by the Laboratoire de Physique Corpusculaire (LPC) of Caen (France) in collaboration with Laboratori Nazionali di Legnaro (INFN) for the SPES project. The design phase started in 2018 and the construction was carried out in 2021. In 2022 the functionality test have been done at LPC and the beam commissioning started. The Beam Cooler is capable to improve the quality of ion beams at low energy in terms of reduction of the transversal emittance and decreasing the energy spread. This document shortly describes the device and the results of the test carried on at LPC during the 2022.

THE PURPOSE

One of the aim of the new project Selective Production of Exotic Species (SPES) is to produce and select new, neutron reach, isotopes [1–4]. The technique adopted to produce these species is the Isotope Selection On Line (ISOL) that postpones the separation of the isotopes after the beam production, using a High-Resolution Mass Spectrometer (HRMS).

In order to allow a good separation of isotopes with high mass number (>100), the transverse emittance and the energy spread of the beam should have very low values, for this reason the BC is located between the ISOL target, i.e. the beam source, and the HRMS.

In the SPES project, in order to have a mass resolution better than dm/m=5×10^{-5}, the features of the beam at the entrance of the HRMS are expected to be $\varepsilon^n_{95\%}$ <8.3×10^{-3} mm mrad and σ_E <1.5 eV.

THE COOLER

The cooler removes the initial features of input beams exploiting the dissipative interaction with light gases (Helium in the presented device) [5]. The cooling process is schematically resumed here: before the beam-gas interaction take place, the ions are slowed down at about 100 eV (the former energy is 40 keV in SPES), then the collisions between the ions and the gas transfer the residual and part of the thermal energy to the gas, finally the ions exit the gas region and are re-accelerate at about the former energy.

During the interaction with the gas, the beam is guided by a long Radio Frequency Quadrupole (RFQ). This component confines the ions in the transverse direction while push them toward the exit thank to 18 electrostatic drops of few Volts, these *kicks* can be obtained on small longitudinal gaps in the RFQ.

If the beam-gas interaction takes place before or after the RFQ, or during the deceleration/acceleration stage the beam features will deteriorate, for this reason special care must be taken to sharply confine the gas. In the presented BC, before and after the RFQ there are two irises that limit the gas diffusion outside the RFQ region (the diameters are 8 mm for the injection and 6 mm for the extraction).

The BC described in this document has the following specifications: the RFQ is 723 mm long, its internal radius is 5 mm, it is composed by 18 sectors, which in turn are composed by 4 rods with a radius of 5.7 mm each. The RFQ is included in the gas chamber which is 730 mm×280 mm×220 mm. Before such a chamber there is the injection part, 470 mm long and composed by, following the beam trajectory, a grounded pipe (388 mm long) and three focusing electrodes. On the opposite side there is the extraction part, symmetrical to the injection one, except for the focusing electrodes that here are two and differently designed. A sketch is in Figure 1.

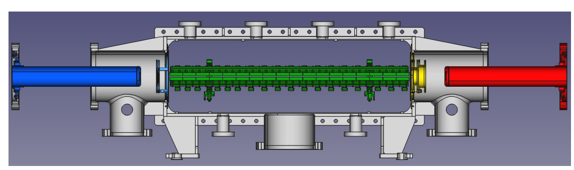

Figure 1: A sketch of the BC. The beam proceeds from the left to the right: the injection ground electrode (red), the injection lenses and iris (yellow), the RFQ composed by 18 sectors, the extraction iris and its lenses (light blue), the extraction ground electrode (blue).

Each compartment (injection, gas chamber and extraction) is equipped with a turbo pump, but during the cooling activity the central turbo pump is closed in order to minimize the gas flowing through the gas waste.

The Mass Flow Controller (MFC) for the Helium injection is a BROOKS SLA5850, which is able to control the gas flow from 0 to 150 slpm with a <1% error.

The entire BC is located on a insulted platform with a High Voltage (HV) power supply by TRANSFO.Industrie able to reach 50 kV with a very small ripple.

The RFQ is powered by a RF generator (a KEYSIGHT 33509B) and a RF power amplifier (a Rohde & Schwarz BBA100-A500 with an output power up to 500 W).

The injection and extraction lenses can be independently polarized with negative values, considering the HV platform as the reference.

* ruzzon@lnl.infn.it

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The remote control of the BC is based on the Epics standard with a client-server configuration: the operator will supervise the devices through a graphic user interface in a client PC, which can run also scripts for automated operations, while all the BC variables are managed in the server [6]. The server is then connected to the devices for the RF setting and to the main PLC, a Modicon Series from Schneider (splitted in ground and HV component), that manages mainly the vacuum devices and the interlocks.

The safety system, namely the management of the access to the HV area, runs on a independent PLC, Pilz this time.

The BC assembly was completed in 2021 at the Labortoire de Physique Corpuscolaire (LPC) at Caen, France and the tests began later in the same year. So far, five experimental sessions were carried on to test both, the safety system and the cooling performance.

EXPERIMENTAL SETTING

The tests are carried on at LPC with a dedicated beam line which is composed, in sequence, by the ion source, the first diagnostic chamber, the beam cooler, a triplet, slits and the second diagnostic chamber.

The source is an IGS-4 by KIM-PHYS, an alkali-metal surface-ionization, able to produce beams of Cs, Li, Na, K, and Rb with an energy from 50 eV to 5 keV. The beam current was limited in the range 50÷60 nA to avoid any problem with the lifetime of the ion cartridge.

In the first diagnostic chamber there is a retractable Faraday cup devoted to measure the beam current entering the BC. In the second diagnostic chamber, located about 1.51 m after the BC exit, there is a second Faraday cup, to read the transmission of the BC, a beam Energy Analyzer (EA) [7] and a pepperpot emittance meter by Dreebit.

The EA reconstructs the energy spread measuring the beam current passing a polarized mesh whose potential sweeps around the expected energy of the beam.

The parameters varied in order to find the best performances are: the BC tension, the injection electrode polarization, the He inflow, the RF tension, the extraction electrode polarization. On the contrary, the beam source is set steadily at 5 keV.

Since the parameters to be managed are numerous, a *compartmentalized* approach was adopted: starting from a reference setting, the injection parameters are varied, then the best configuration is kept and the RFQ chamber parameters are modified, finally its most interesting setting is kept and the attention is given to the extraction variables.

As a closing remark, the lacking of steerers imposes the use of unbalanced biases in the triplet quadrupoles which can results in an aberrated beam and thus in an overestimation of the transversal emittance.

RESULTS

The first ion analysed is the $^{133}Cs^{+}$. As stated before, the determination of the sweet spot starts from a reference configuration which has the injection electrodes set to 100 V, 100 V, 192 V; the RFQ DC biases set to 16 V, 12 V, 6 V, 4 V and 2 V; the extraction electrodes polarized to 436 V, 230 V; the He flow at 11 ml/min and the RF signal at 3 MHz with an amplitude of about 1750 V.

The variation of the injection setting should impact only the transmission and thus other measures are not evaluated. Figure 2 shows the transmission as a function of the platform tension. The best setting resulted in the range 4900÷4930 V.

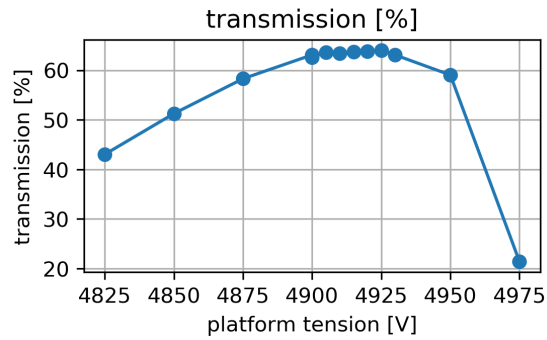

Figure 2: The transmission of the BC, in ordinate, as it varies with the platform tension (abscissa).

After determining the best BC potential, the bias of the injection lenses are varied, the first and the third electrodes are kept at the same potential. The results are in Figure 3: best transmissions are in a ridge slightly peaked at Inj_1=Inj_3=175 V and Inj_2=25 V with a transmission of 65 %.

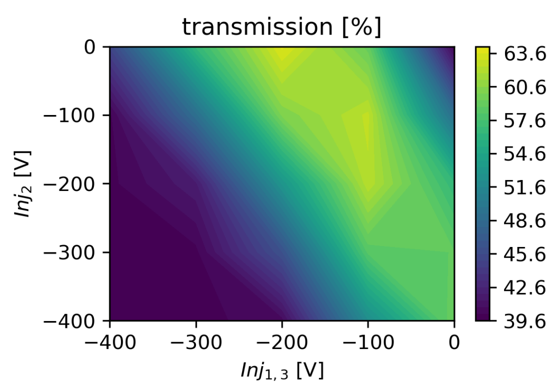

Figure 3: The transmission of the BC: the colour scale represents the transmission in percent as it varies with the injection electrodes tension (the two Cartesian axis).

After the injection section, the RFQ chamber can be analysed. In this case the variables are the pressure, expected to be the major player, and the q parameter, varied changing only the RF amplitude.

For the sake of completeness the definition of the Mathieu parameter is: $q = 4eV_{rf}/mr_0^2\omega_{rf}^2$ with e the fundamental charge, V_{RF} the RF amplitude, m the ion mass, r_0 is the internal radius of the RFQ and ω_{rf} the RF pulse.

Unlike the previous section the most important measure is the energy spread and since the Faraday cup is not available

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during the spread measurement, the behaviour of the transmission can be deduced from the maximum current read by the EA.

Results are reported in Figure 4 and in Figure 5. The first shows the trend of the energy spread depending on the gas flow (abscissa) and the RF amplitude (ordinate) while the second represents the highest current captured by the EA.

As expected, the energy spread results higher for very low gas flow, this is due to the insufficient number of collisions between the ions and the gas atoms; once the gas flow is set higher than 14 ml/min the spread does not improve any more and instead it worsens very slowly. On the other side the transmission reach a maximum with a gas flow at about 14 ml/min while it is quickly reduced as the gas flow rises. In contrast the Mathieu parameter q seems do not play an important role.

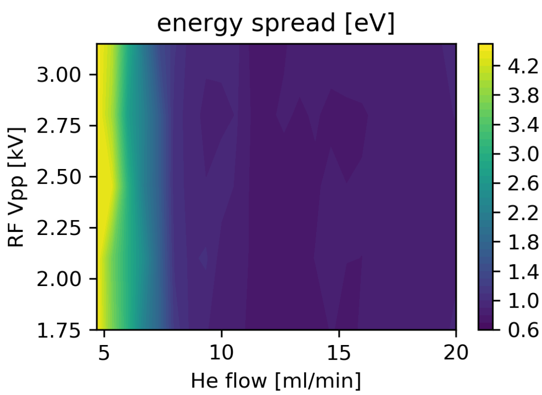

Figure 4: The energy spread varying the He flow (abscissa) and the q parameter (ordinate).

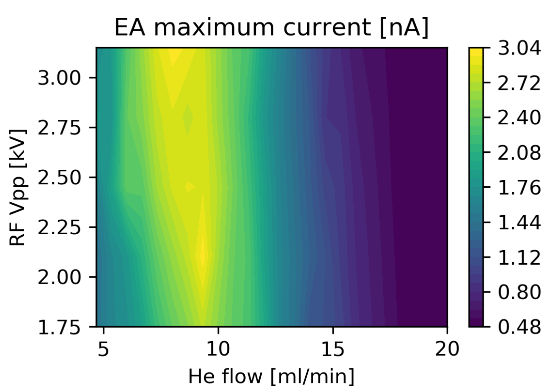

Figure 5: The highest current captured by the ESA as the He flow (abscissa) and the RFQ tension (ordinate) vary.

In the range considered, the best result is reached with a gas flow of 14 ml/min and a V_{rf}^{pp} equal to 2100 V: the spread is about 0.7 eV and the transmission is 64 %.

Besides the systematic scan reported in the two plots, other measures were taken with different quadrupole frequency. The performances of these configurations are reported in Table 1.

Table 1: Transmission and Spread Results for Different Configurations

V_{RF}^{pp} [kV]	f_{RF} [MHz]	q	Flow [ml/min]	σ_E [eV]	Transmission [%]
0.23	2.5	0.11	15	0.76	18
0.29	2.5	0.14	15	0.74	30
0.91	3.0	0.30	11	0.63	62
1.41	4.5	0.20	12	0.60	62

The extraction electrodes cause only a slight variation in energy spread and transmission and their setting does not affect the overall cooling performance. The best optimized setting, mainly considering the emerging beam dimension, resulted in Ext_1 = 600 V and Ext_2 = 200 V.

Finally some measures of the transverse emittance for the most promising configurations were done, the results are in Table 2, they are reported in relation of the parameter q and of the gas flow. The variation of q was performed changing the RF amplitude while the pressure was kept at 14 ml/min; in the case of the variation of the gas flow, the RF configuration was kept constant at V_{RF}^{pp}=0.91 kV and f_{RF}=3 MHz, i.e. q=0.3.

Table 2: Emittance as a function of the parameter q (first two rows) and of the gas flow (last two).

q	0.225	0.45	0.68	0.9
$\tilde{\varepsilon}^n$	$1.5{\cdot}10^{-3}$	$1.5{\cdot}10^{-3}$	$1.9{\cdot}10^{-3}$	$2.1{\cdot}10^{-3}$
flow [ml/min]	10	14	18	20
$\tilde{\varepsilon}^n$	$1.6{\cdot}10^{-3}$	$1.5{\cdot}10^{-3}$	$1.9{\cdot}10^{-3}$	$2.0{\cdot}10^{-3}$

These last data confirm the best results are reached keeping the q parameter fairly low and that the pressure of the cooling gas must be sufficient to have a sufficient action, but that it can have negative effect over a threshold which is, in this case, around 14 ml/min.

CONCLUSIONS

In this paper the cooling performance measured so far of the new SPES Beam Cooler are presented.

As reported above the results fulfil the requirements of the SPES selection system for the $^{133}Cs^{+}$beam, but other measures using different ions, like $^{39}K^{+}$, have to be done in order to end the commissioning and to verify that all the expected beams can be properly selected by the HRMS.

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