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THE C70XP INJECTION LINE TRANSVERSE DISTRIBUTION STUDY AND IMPACT

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Abstract

The C70XP is a cyclotron operated for production of radionuclides in nuclear medicine, for research in physics, radio-chemistry and biology. It aims at providing high-intensity beams to the various experiment for long or very short time runs. The beam transverse distribution, e,g. homogeneity and emittance, has a great impact on the experiments. The ion source and subsequently the injection line, which can hold 4 types of particles (HH+, D-, He2+ and H-), being the first stage of the accelerator defining the beam, are therefore of particular focus for the beam studies.

Thus, a first study of the transverse beam distribution in the injection line has been measured with an Allison-type emittance-meter. Additionally, various simple shape collimators have been used and their impact has been measured in the extraction beam line. These studies have also been combined with multiple magnets tuning simulating various operating mode.

A model of the injection line based on G4Beamline has been performed. The experimental and simulation results are given in this paper as well as the on-going studies for a potential future collimator.

INTRODUCTION

The C70XP cyclotron of Arronax Public Interest Group (GIP) aims to provide a well-defined transverse beam characterized by low emittance and high current. To achieve these objectives, several studies are underway on different parts of the cyclotron, mainly the beamlines and the injection line. It is on the latter subject the paper is focused.

Measurement campaigns have been performed with an Emittance-Meter (EM) and simple instrumented collimators in the injection line. The first campaign has revealed the presence of several current density spots within the beam in the injection line and has shown that modification of the operational settings can be applied to reduce the spots to a single one. , The measurements with collimators have pointed-out to the possibility of reducing the transverse emittance at the end of line, by performing geometric beam cuts-out.

These findings have led to the definition of a permanent future collimator installed in the injection line. This apparatus may potentially allow to progress on our studies and also to further satisfy the requirements of the quality of the beam e.g. homogeneity, low emittance and high intensity. A first design, based on the analysis of the experimental results and the simulation of the injection line, is being addressed in this paper.

EMITTANCE MEASUREMENT CAMPAIGN

A 2D (x,x') Alison-type EM, later named EM, built by the EmitM collaboration [1] has been installed in the injection line of the C70XP for a two weeks measurement campaign [2]. For this campaign, reference measurements were performed using standard settings for radio-isotope production. Additional measurements were done where the settings of the various magnetic and electric fields, from the components of the source and the injection line, were modified. The analysis of the measurements has helped to highlight the outcomes of two methods used for reducing the transverse emittance: the first one uses the tuning of the components and the second one applies geometric cut-out of the beam.

The Injection Line Tuning

An example for the tunings, is the H- ion source electric field settings (high voltage, puller, suppressor) which leads to the emergence of several intensity density spots. One of the reference measurements of the campaign is shown in Fig. 1, displaying two intensity density spots in red.

With the tuning of the fields, a single spot could be obtained as shown on the right-hand side of Fig. 1. The optimisation of the source also produced a reduction of the measured fitted emittance at 39.35%, from 20.3 mm.mRad for the reference settings to 7.6 mm.mRad for the optimised ones. The increase of the beam intensity, measured downstream the entrance of the cyclotron, is of 28%.

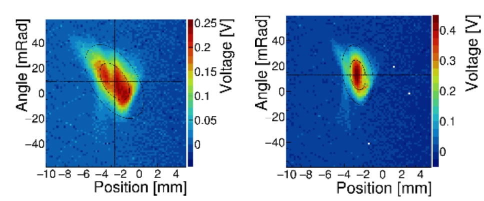

Figure 1: Transverse emittance measurements, with the reference settings on the left and optimised ones on the right side.

Geometric Beam Cut-Out

During the campaign, a slit with an opening of 4 mm was installed upstream of the EM (above the buncher [2]), perpendicular to the opening slit of the EM, to explore the cut-out effects on the measured beam transverse emittance. Fig. 2 shows, on the left, the reference measurements of the day, containing the two intensity density spots with an emittance at 39.35% of 15.6 mm.mRad. On the right, with the slit, the EM measurement displays the single main spot with an emittance of 4.4 mm.mRad. The perpendicular

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positioned slit has the effect of cleaning the emittance but at the same time reduce drastically the intensity.

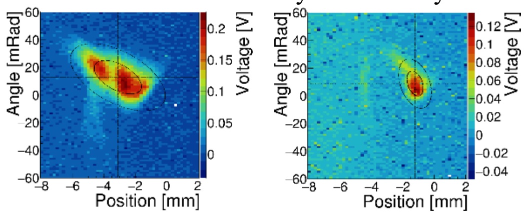

Figure 2: Transverse emittance measurement (x,x'): on the left, a reference beam with multi-density spots and on the right, the result with a four mm wide slit.

COLLIMATORS EFFECT ON EMITTANCE

Additional campaigns were carried out without the EM to allow extraction of the beam at high energy and with various size and shape of simple collimators. Beside installation testing, the goals were to check their capacity to give information on the beam, being instrumented, and to get a first insight of their effect on the beam at the end of the beamlines. These collimators have a circular aperture of diameter ϕ or a slit installed at the location of the previous study. A two-stages collimators, constituted of a large aperture (ϕ=25, 30, 35mm) collimator, installed on the top of the buncher and a small aperture one (ϕ=10 mm) located below a faraday cup, was also used.

Experimental Result

To measure the impact of a collimator on the emittance at the end of the beam-lines, quadrupole scans [3] were performed using the four fingers collimator close to the target at the end of the beam line. The results of the technique, named "Collimator Based Quad Scan Width" (CBQSW) [4], are inversely correlated to the beam emittance. The measurements which are performed independently on various high-intensity beamlines (P3, A1, and P2) [5] and collected together to maximize the statistics, though depends on the experimental details. The CBQSW measurements are gathered, according to the size and shape of the collimators, in Fig. 3. When several measurements have been done, error bars are calculated and corresponds to the standard deviation ±σ (68%) of the distribution.

As a comparison to CBQSW with collimators, measurements carried out during standard irradiation runs and without collimators (on Fig. 3 right-hand), are shown. The results give here no dependence from the beamline. The single circular collimators (with ϕ=15, 25) gives a similar width value than the measurements without collimator. With the two-stage collimators, the disparity in the results is exposed.

Discussion and Experimental Observation

The above results point out to the possibility of modifying the beam characteristics in the injection line and keeping partly this gain down to the targets. Though a large instrumented aperture collimator, used to protect the buncher, is not sufficient to ensure that the gain is kept and that a large collimator with a relatively narrow aperture, can lead to smaller emittance in the cyclotron extraction, at the expanse of a thorough optimisation.

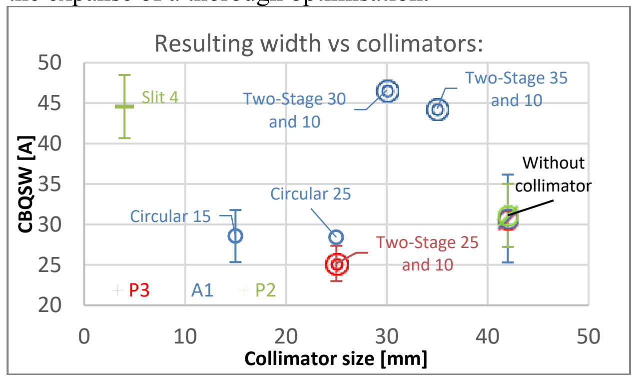

Figure 3: The CBQSW according to the size diameter of the collimators and their shapes at high-intensity beamlines.

The (x,x') transverse emittance measurement, without the slit and detailed in [6], shows a dependence as the source power increases. This dependence was not confirmed during later quadrupole scan at the end-of-beamline, inferring a washing effect from the cyclotron.

Also, the work presented at low intensity, using Gafchromic™ film, and with the slit, have exhibited an increase of beam spatial uniformity [6]. The result is consistent with the other emittance measurements inside the injection line with the slit.

These two previous observations suggest that, in the absence of measurements of the emittance in the injection required for the optimisation of the beam with the injection and source tuning setup, the technique, using a geometrical cut-out, could still be favorable. This has to be explored further on with a permanent tool such as a very compact instrumented and adjustable jaw-like system.

SIMULATION

Model

To estimate the y-emittance and the beam shape in the xy-plane, a model of the injection line is built within G4beamline (G4BL) [7] and performs H- beam propagation. The model is based on the implementation of the injection line geometry and the simulated magnetic *B*-fields, as described in [8]. The *B*-fields maps for quadrupoles, dipoles and solenoids were included using calibrated multi-axial measurements when available and, are linearly adjusted according to the experimental settings at the time of the emittance measurements. A single coefficient is used, representing a homogenous B-field for the steerers. The external magnetic field of the cyclotron main coil is not included, although experimental measurements indicated a peak value of 21 mT at the location of the EM and preliminary simulation indicates that this field modifies slightly the trajectory of the particles. Its setting was not changed during the considered measurements here.

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The Source Output Reconstruction

A code has been written to take as input a test-beam, generated at the source, with an emittance randomly distributed. This test-beam is propagated within the model to the location of the EM. The simulated output (x,x') is then compared to the experimental measurements, as shown in Fig. 4.

The 5000 particles that constitute a distributed test-beam are assigned position (e.g. μ_x, μ_y), dispersion (e.g. $\mu_{x'}$, $\mu_{y'}$) twiss parameters (α_x, α_y) mean values. Values are also assigned for the simulated magnetic fields for the steerers and solenoids. A similarity value is calculated taking as inputs the simulated distributions, obtained with three solenoids settings, and three equivalent experimental distributions from the EM. This operation is performed with new inputs distribution values and is repeated as many times as necessary until a solution converged.

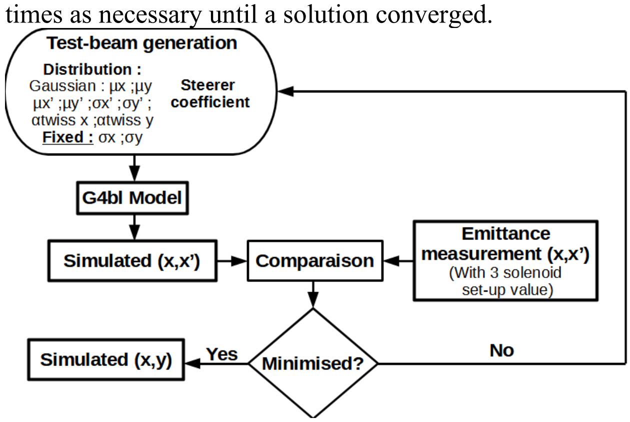

Figure 4: Simulation and experiment flowchart to obtain the (x,y) distribution.

The Result of the Simulation:

In Fig. 5, an example of the obtained results is presented, with, on the top-left the corresponding emittance measurement, and the three other plots being the resulting simulation distributions (x,x', y,y' and x,y). This example shows that the beam can be constituted of two high density spots distinct in *x* and *y* positions.

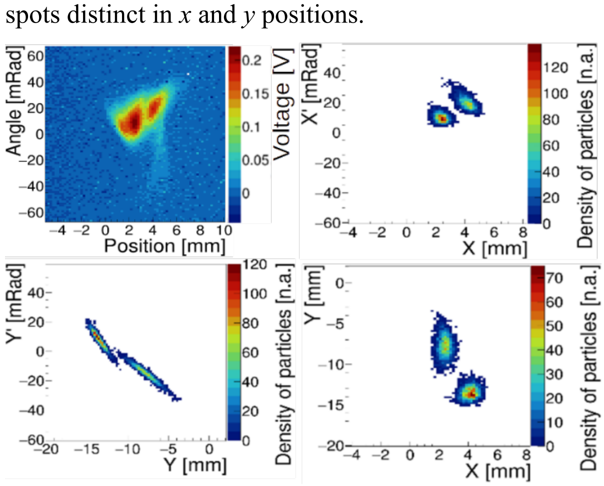

Figure 5: On the top left, a (x,x') transverse emittance measurement and the equivalent result of the beam simulation in (x,x'), (y,y') and (x,y).

The simulation results are consistent with the experiments provided that the operational setup is within 5% of the reference inputs. This gives a limited framework to go forwards as the two spots can be potentially isolated using a collimator. This isolation capacity could also explain the results of the CBQSW with a slit.

THE FUTURE COLLIMATOR

The future collimator, installed at the same location as the EM, should have the following capacity:

- Based on the experiments with several types of collimators, a straight slit shape seems appropriate to achieve geometric cut-outs to reduce the emittance.
- Based on the emittance measurements, the collimator should give an approximate indication of the beam shape on a projected axis (x or y). For this, it has to be constituted of two adjustable and instrumented fingers minimum. As it has to help the tuning in the injection line, a scanning procedure has to be developed.
- Simulation results support that the collimator should rotate around x or y axis, to isolate each beam spots.
- The collimator should be able to withstand high beam power, around 100 Watts at maximum and still be compact (40 mm available vertical space) including its cooling system, supports and movers.

An aperture defined by an instrumented four-jaws (independent fingers) slit which that can be centred at various transverse positions is thus favored as an adequate first prototype.

CONCLUSION

Several experiments, including field setup modification in the injection line, have been conducted with an emittance-meter and collimators with various shapes and sizes. A simulation tool box has also been devised to replicate a selection of the emittance-meter results. The comparison with the experiments has been used to expand the phase-space output reached such that the simulation could be used for exploring the usage of a collimator.

Although, the simulation and methodology are in progress, its first indication, combined with simple collimator experiments, support that a compact instrumented and adjustable 4-jaws collimator would allow to select parts of the beam, to reduce the emittance and to increase the homogeneity of the beam. This is viewed as a future improvement for the production of radio-isotope, provided sufficient beam intensity is sent to the target.

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REFERENCES

[1] F. R. Osswald, T. Adam, P. G. Graehling, M. Heine, C. Maazouzi, and E. K. Traykov, "Transverse Phase Space Scanner Developments at IPHC", in *Proc. IBIC'19*, Malmö, Sweden, Sep. 2019, pp. 293-296. doi:10.18429/JACoW-IBIC2019-TUPP007

[2] F. Poirier *et al.*, "Installation, Use and Follow-Up of an Emittance-Meter at the Arronax Cyclotron 70XP", in *Proc. IPAC'21*, Campinas, Brazil, May 2021, pp. 877-880. doi:10.18429/JACoW-IPAC2021-MOPAB277

[3] M. Minty and F. Zimmermann, "Measurement and Control of Charged Particle Beams", Springer, New York, 2003.

[4] A.Sengar, "Development of Beam Diagnostics and Studies of Transverse Beam Dynamics Towards High-Intensity Operations in the Beamlines of the C70XP", Ph.D. thesis, Phys. Dept., Subatech, Nantes, France, 2021.

[5] F. Haddad *et al.*, "ARRONAX, a High Intensity Cyclotron in Nantes", presented at the ND 2007, International Conference on Nuclear Data for Science and Technology, Nice, France, Apr. 2007,

[6] T. Durand *et al.*, "Study of Injection Line of the Cyclotrons C70XP of Arronax", in *Proc. HIAT'22*, Darmstadt, Germany, Jun.-Jul. 2022, pp. 100-103. doi:10.18429/JACoW-HIAT2022-TUP14

[7] T. J. Roberts and D. M. Kaplan, "G4Beamline Simulation Program for Matter-dominated Beamlines", in *Proc. PAC'07*, Albuquerque, NM, USA, Jun. 2007, paper THPAN103, pp. 3468-3470.

[8] F. Poirier *et al.*, "The Injection and Chopper-Based System at Arronax C70XP Cyclotron", in *Proc. Cyclotrons'19*, Cape Town, South Africa, Sep. 2019, pp. 159-161. doi:10.18429/JACoW-CYCLOTRONS2019-TUP006