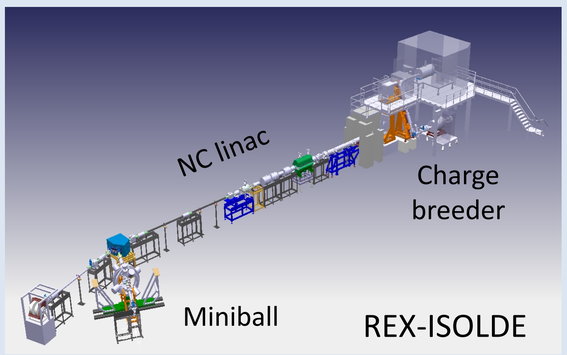
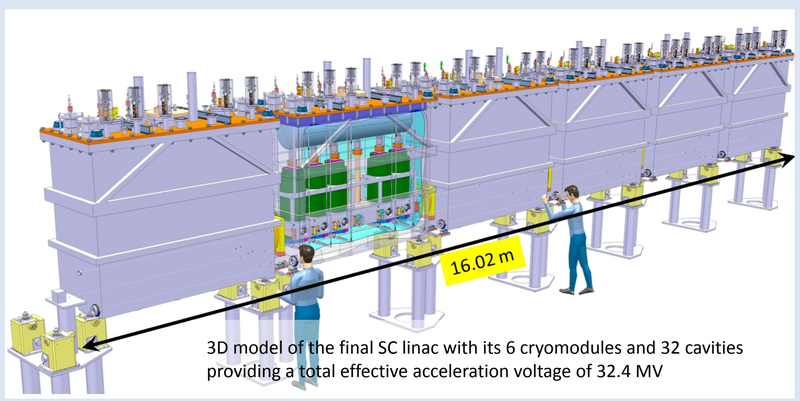
# TRANSVERSE EMITTANCE MEASUREMENTS OF THE REX-ISOLDE BEAMS IN PREPARATION FOR THE HIE-ISOLDE COMMISSIONING

D. Voulot, M.A. Fraser, D. Lanaia, T. Olsson, CERN, Geneva, Switzerland

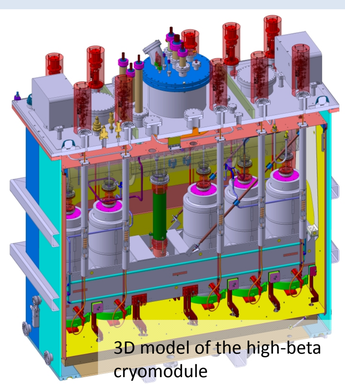
## The HIE-ISOLDE superconducting linac




REX-ISOLDE is the CERN Radioactive Ion Beam post-accelerator. It provides RIBs at energies up to 3 MeV/u for A/q ≤ 4.5 [1]. With the extension of the charge-breeding performance for ions with large A and the increasing number of isotopes available at ISOLDE, an energy upgrade was necessary to make full use of the available beams.




3D model of the final SC linac with its 6 cryomodules and 32 cavities providing a total effective acceleration voltage of 32.4 MV

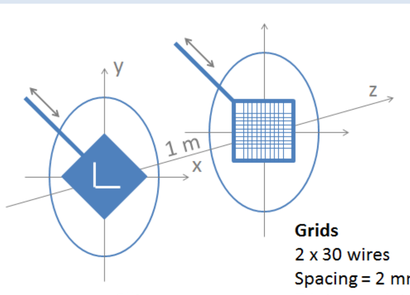


3D model of the high-beta cryomodule

The new High Intensity and Energy (HIE-ISOLDE) superconducting linac will be installed downstream the existing linac and extend the energy range to 5.5 and eventually 10 MeV/u for ions with A/q ≤ 4.5 keeping full flexibility and improving the beam quality [2] [3].

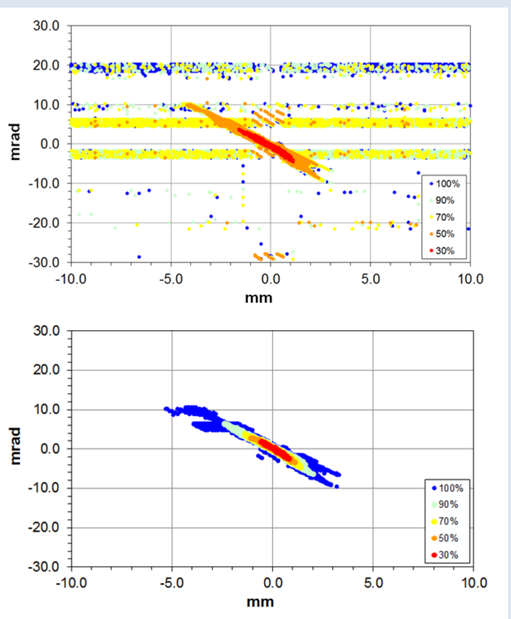
The accurate measurement of the transverse emittance of the accelerated beams is essential to assess the performance of the linac and the quality of the delivered beams. It is also a key parameter for the design of the HIE-ISOLDE linac.

## Slit-grid emittance measurements

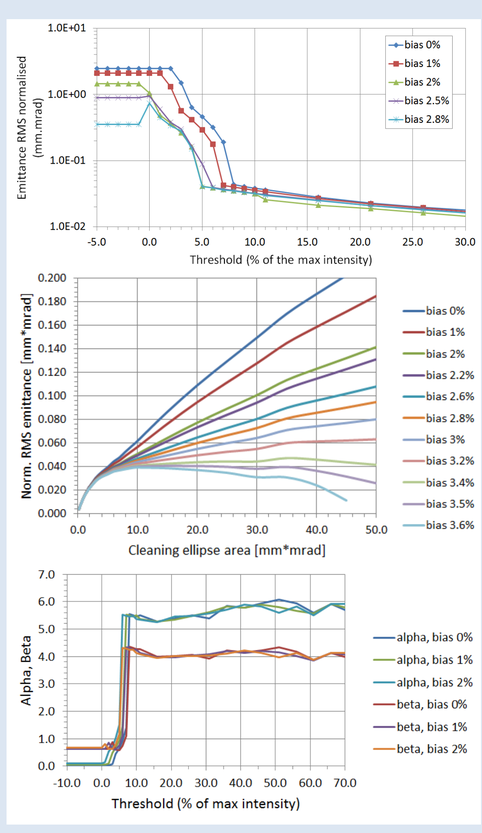



Left: Principle of slit-grid emittance measurement and specification of emittance-meter.
Right: emittance-meter device.

Due to the low intensity nature of the RIBs typically accelerated at REX-ISOLDE, a stable pilot beam extracted from the rest gas of the EBIS charge breeder is normally used to set-up the linac. These beams have a typical intensity of 10-100 epA and should represent well the beam characteristics of the charge-bred beams. The stable beam intensity can be increased by injecting gas directly in the electron beam region of the source but this has the disadvantage of degrading the EBIS beam emittance through electron beam compensation. For this reason the beam intensity was practically limited to 500 epA – 1000 epA.




Emittance scan of a 500 epA beam of Ne5+ at 2.85 MeV/u. Raw data (top), emittance plot after background suppression (bottom).




Normalised RMS emittance and Twiss parameters calculated as a function of bias (fixed offset applied to the full data set) and threshold (values below which data points are ignored) illustrating the stability of the measurement. The normalised RMS value of 0.04-0.05 suggested by the test, is in good agreement with the value of 0.049 mm.mrad obtained after arbitrarily clipping the phase space area outside of the beam.

## Quadrupole scan measurements

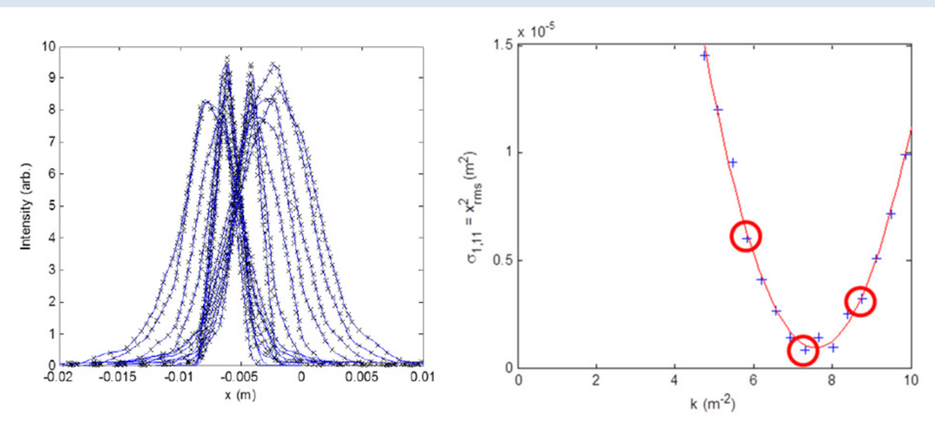
The beam can be represented by the $\sigma$-matrix:

$$\sigma = \begin{pmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{21} & \sigma_{22} \end{pmatrix} = \begin{pmatrix} \beta\epsilon & -\alpha\varepsilon \\ -\alpha\varepsilon & \gamma\epsilon \end{pmatrix}$$

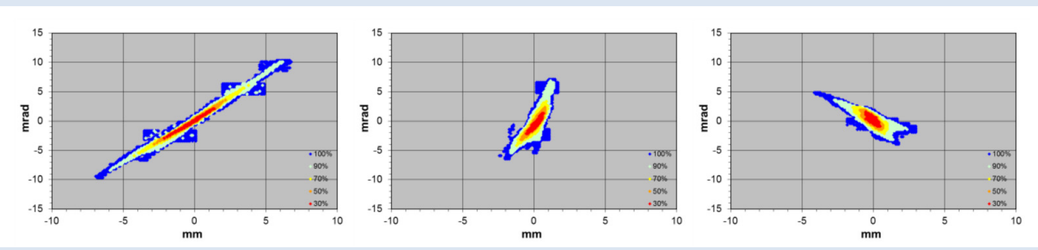
where $\det(\sigma) = \epsilon^2$. The beam downstream a beam line can be calculated from the R-matrix representing this beam line and the $\sigma$-matrix representing the input beam: $\sigma^{(2)} = R\sigma^{(1)}R^T$. For a thin lens followed by a drift $d$ the R-matrix will be:

$$R = \begin{pmatrix} 1 & d \\ 0 & 1 \end{pmatrix}\begin{pmatrix} 1 & 0 \\ -1/f & 1 \end{pmatrix} = \begin{pmatrix} 1-d/f & d \\ -1/f & 1 \end{pmatrix}$$

The $\sigma_{11}$ element can be written explicitly taking $f = 1/kl$ where $l$ is the quadrupole length. The $\sigma$-matrix element can be calculated for the RMS ellipse from the distribution's second moments and in particular we have: $\sigma_{11} = \langle x^2 \rangle$. Thus from a set of beam profile downstream the quadrupole, recorded for different focussing strength $k$, one can calculate the $\sigma$-matrix element and emittance of the RMS beam at the entrance of the quadrupole.




Left: Horizontal beam profile for different quadrupole current.
Right: $\sigma_{11}$ as a function of normalised quadrupole gradient $k$.
Bottom: Phase space portrait for the circled data point, illustrating the bunch rotation.

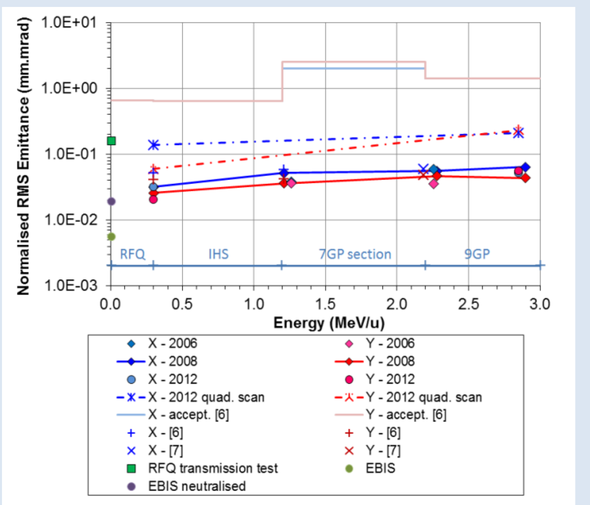



| Energy (MeV/u) | Plane | Method | $\varepsilon^n_{RMS}$ (mm.mrad) | Ratio |
|---|---|---|---|---|
| 2.85 | X | Quad-scan | 0.210 | 4.1 |
| | | Slit-grid | 0.052 | |
| | Y | Quad-scan | 0.230 | 4.2 |
| | | Slit-grid | 0.055 | |
| 0.30 | X | Quad-scan | 0.140 | 4.4 |
| | | Slit-grid | 0.032 | |
| | Y | Quad-scan | 0.060 | 3.0 |
| | | Slit-grid | 0.020 | |

The emittances measured with the quadrupole-scan method were found to be three to four times larger than the ones measured with the slit-grid method; this is true for both energies and for the two planes.

The discrepancy can be explained either by an error on the profile measurement or due to the intensity limitation of the slit-grid method which could lead to an underestimation of the beam intensity in the tails of the distribution where the background is significant. A comparison of the profile reconstructed from the emittance data and the profile measurement seems to contradict this hypothesis. This should be confirmed by an independent measurement of the beam profile, which will be available in HIE-ISOLDE.

## Summary




The transverse emittance measurements obtained at REX-ISOLDE are plotted together with some of the values used in the REX-ISOLDE design studies.

1. The measurements are consistent with a normalised RMS emittance of 0.04-0.05 mm.mrad
2. The quadrupole-scan measurement are in disagreement, but represent a promising technique for future emittance measurements at HIE-ISOLDE.

## Acknowledgement

We acknowledge funding from the Swedish Knut and Alice Wallenberg Foundation (KAW 2005-0121) and from the Belgian Big Science program of the FWO (Research Foundation Flanders) and the Research Council K.U. Leuven.
We would like to acknowledge as well the receipt of fellowships from the CATHI Marie Curie Initial Training Network: EU-FP7-PEOPLE-2010-ITN Project number 264330.

## References

[1] D. Voulot et al, Nucl. Instrum. Meth. B 266, p. 4103, 2008.
[2] Y. Kadi et al, IPAC'12, MOOBA02, New Orleans, vol. 34, 2012.
[3] W. Venturini Delsolaro et al, THIOA03, these proceedings., 2014.