# Study of the Transverse Beam Emittance of the Bern Medical Cyclotron

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## 1. The Bern cyclotron laboratory

The cyclotron laboratory at the Bern University Hospital (Inselspital) performs GMP radioisotope and PET radiotracer production in parallel with multi-disciplinary research [1]. The core of the facility is the IBA Cyclone 18 MeV cyclotron (Fig. 1).

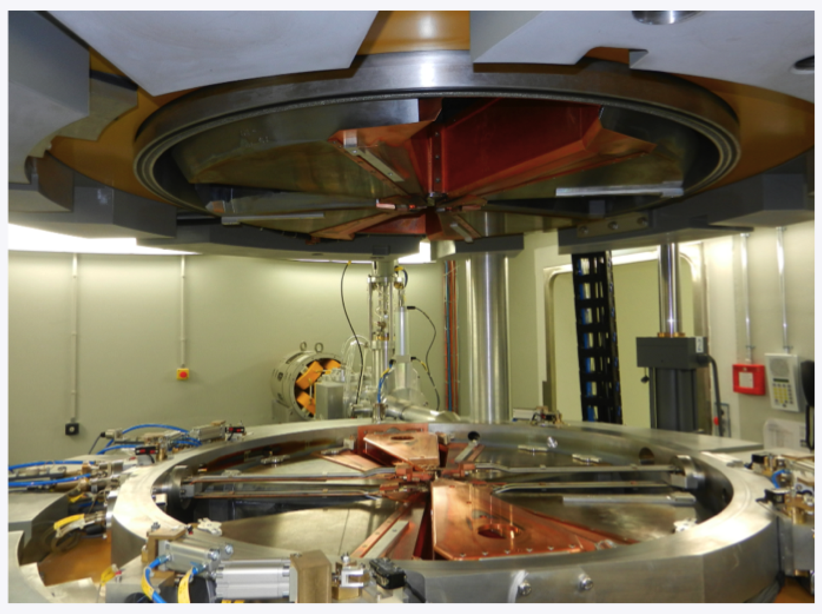

**Figure 1:** The Bern cyclotron opened during commissioning.

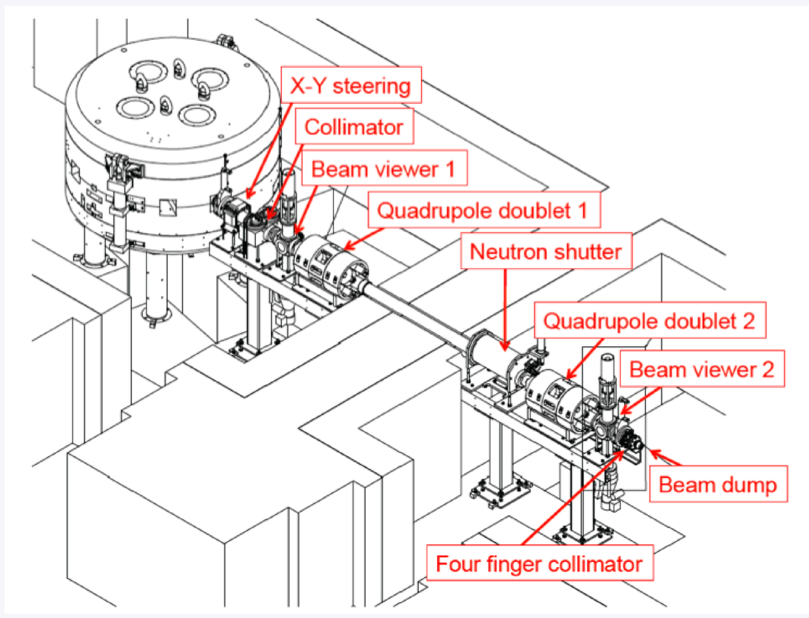


**Figure 2:** Schematic view of the Beam Transport Line.

The cyclotron laboratory is equipped with a 6.5 m long Beam Transport Line (BTL) ending in a separate bunker (Fig. 2), which is used for research activities as studies of the transverse beam emittance.

## 2. Transverse profiles and statistical approach

Transverse beam profiles were measured along the BTL by means of the UniBEaM detector - a beam profiler developed by our group (Figs. 3 and 4). It is based on doped silica and optical fibers and its first prototype is described in [2].

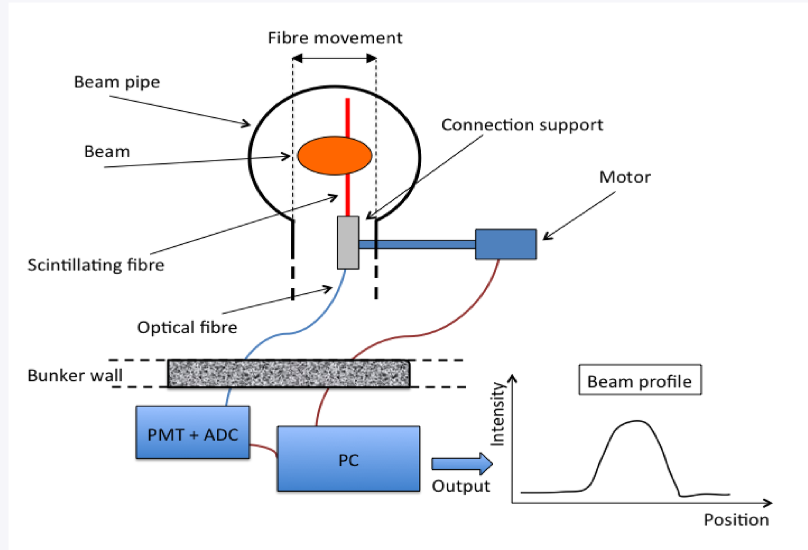


**Figure 3:** Scheme of the UniBEaM detector.

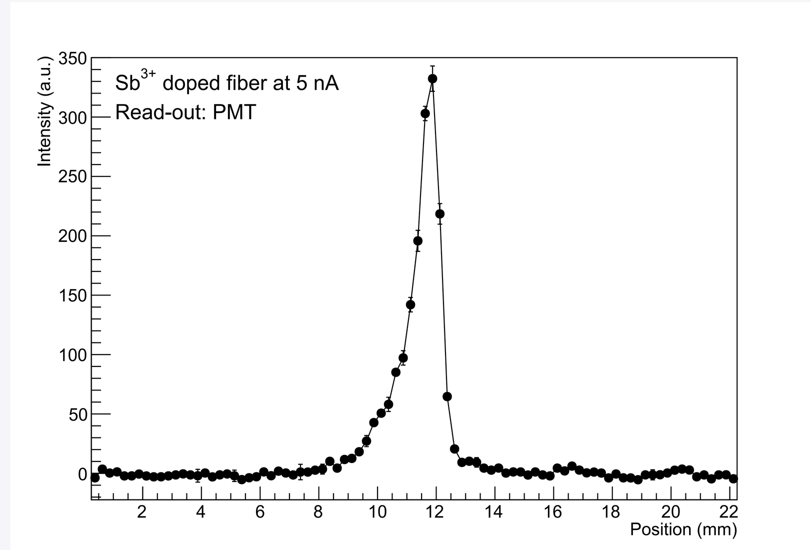


**Figure 4:** Profile of a 5 nA beam measured with the UniBEaM detector.

The profiles measured along the BTL are far from being Gaussian mostly due to the energy spread of the beam obtained by stripping $H^-$ ions. For the transverse beam emittance measurements, an appropriate estimation of the beam size from measured beam profiles is crucial. The variance calculated for each beam profile histogram was chosen as the best estimator of the beam width. The transverse RMS emittance is a function of the variance $\langle x^2 \rangle$:

$$\varepsilon_{rms} = \sqrt{\langle x^2\rangle\langle x'^2\rangle - \langle xx'\rangle^2}.$$

## 3. Quadrupole variation method

The UniBEaM detector was located at a fixed position along the BTL after the last focusing section. The current of the last quadrupole was varied and the beam profiles were measured (Fig. 5). The quadrupole strength $k$ is related to the current. The measurements were performed for both horizontal and vertical plane by rotating the UniBEaM profiler by 90°. A beam current of 250 nA was chosen for the experiment.

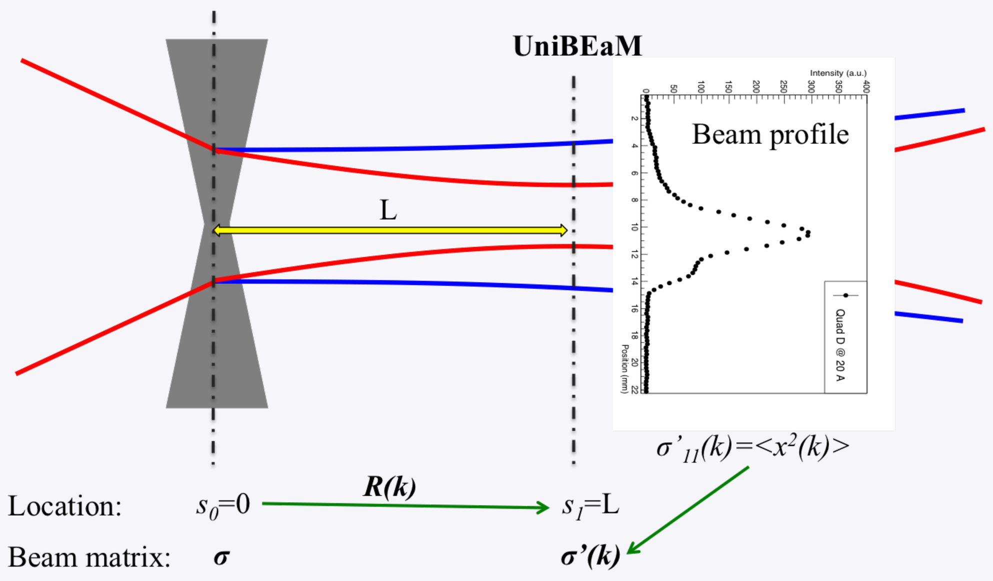


**Figure 5:** Variation of quadrupole strength for the measurement of the transverse beam emittance.

Matrix $\sigma'(k)$ at the location $s_1$:

$$\sigma'(k) = R(k)\sigma R(k)^T.$$

The $\sigma'_{11}(k)$ component is:

$$\sigma'_{11}(k) = f(k; \sigma_{11}, \sigma_{12}, \sigma_{22}).$$

The function $f(I; \sigma_{11}, \sigma_{12}, \sigma_{22})$ was fitted to the data (Fig. 6).

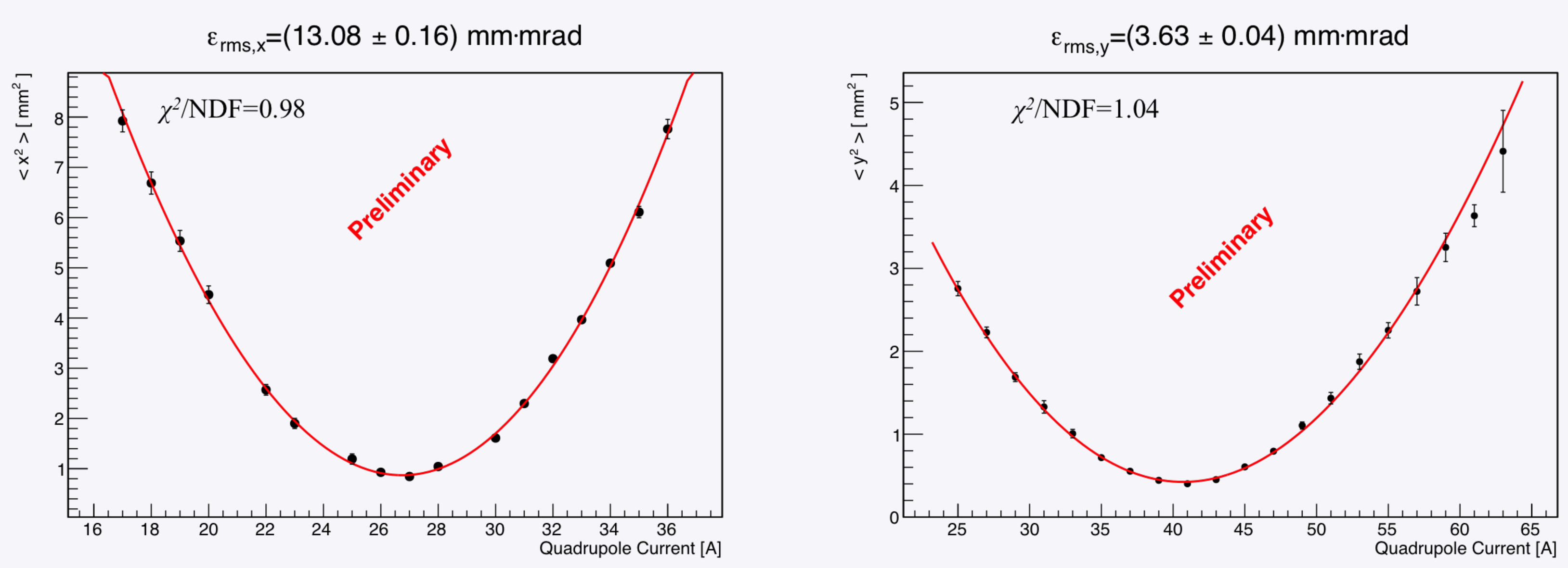


**Figure 6:** Variance as a function of the quadrupole current for the horizontal (left) and vertical (right) plane obtained in the quadrupole variation method. The red lines correspond to the best fits.

## 4. Multiple profiler method

Four UniBEaM detectors were installed on the BTL. For a beam current of 250 nA, beam profiles were measured at four locations around a beam waist (Fig. 7). The UniBEaM monitors were rotated by 90° for measurements in the vertical plane.

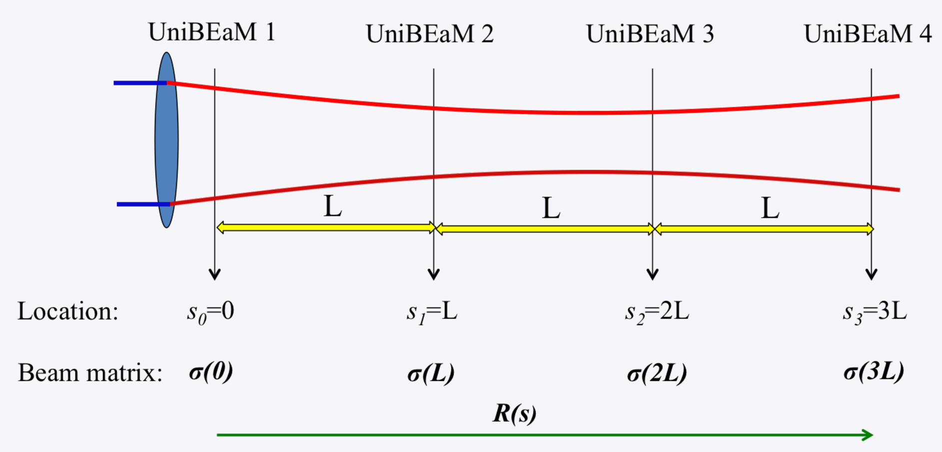


**Figure 7:** Multiple beam profilers for the measurement of the transverse beam emittance.

Matrix $\sigma(s)$ at the location $s$:

$$\sigma(s) = R(s)\sigma(0)R(s)^T.$$

The $\sigma_{11}(s)$ component is:

$$\sigma_{11}(s) = \sigma_{22}(0)s^2 + 2s\sigma_{12}(0) + \sigma_{11}(0).$$

The above quadratic function was fitted to the data (Fig. 8).

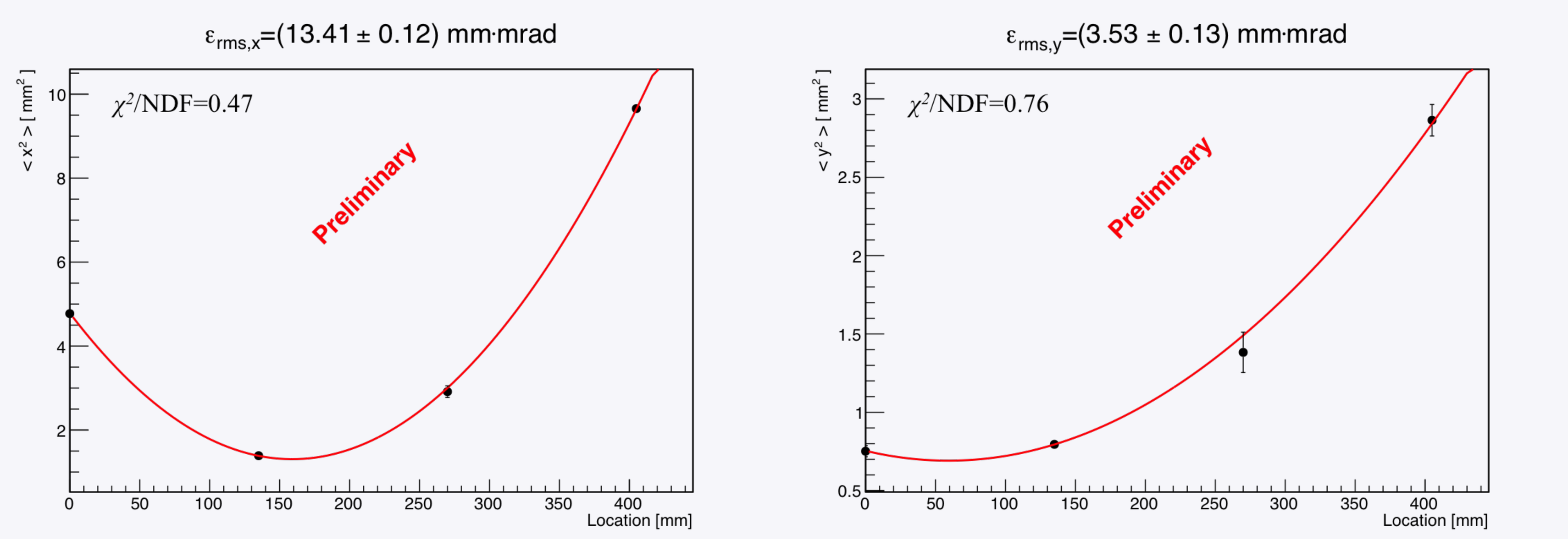


**Figure 8:** Variance as a function of the quadrupole current for the horizontal (left) and vertical (right) plane obtained with the use of multiple UniBEaM detectors. The red lines correspond to the best fits.

## Conclusions

The transverse RMS beam emittance of the Bern medical cyclotron was measured for the first time by using the UniBEaM profiler developed by our group. Two different methods - quad variation and multiple profilers - were applied. The results were found to be in agreement within $1.65\sigma$ and $0.71\sigma$ for the horizontal and vertical plane, respectively. The emittance in the horizontal plane is ∼4 times larger than the one in the vertical plane. This is due to the acceleration in the horizontal plane which causes an increase of the particle position spread.

## References

[1] S. Braccini, *The New Bern PET Cyclotron, its Research Beam Line, and the Development of an Innovative Beam Monitor Detector*, American Institute of Physics (AIP) Conf. Proc. 1525 (2013).

[2] S. Braccini et al., *A beam monitor detector based on doped silica and optical fibres*, 2012 JINST 7 T02001.