TRANSVERSE PHASE SPACE TOMOGRAPHY IN TRIUMF INJECTION BEAMLINE *

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Abstract

By tomography is meant the reconstruction of a 2-dimensional distribution from a number of 1-dimensional projections. In the case of transverse phase space, one records many profiles while varying a focusing device such as a quadrupole. Our aim was to investigate the two transverse phase space distributions in our 300 keV H^- beamline. We performed a series of measurements of beam profiles as a function of the voltage of an electrostatic quadrupole and used these along with the corresponding calculated transfer matrices in an iterative program based upon the Maximum Entropy algorithm, to find the phase space distributions. As well, we made measurements using an Allison-type emittance scanner to scan both planes. In this paper we present the details of these measurements, calculations, and we compare the two techniques.

MENT TOMOGRAPHIC RECONSTRUCTION

Knowledge of the detailed phase space density distribution is useful to understand subsequent evolution of the beam. In the TRIUMF 300 keV H^- injection beamline, we applied the Maximum Entropy (MENT) technique [1, 2] to reconstruct the 2-D phase space from a number of 1-D projections of beam under various viewing angles. This was done by taking a series of measurements of beam profiles with a wire scan monitor as a function of voltage setting of an upstream electrostatic quadrupole.

Refer to Fig. 1. We varied quad Q111's voltage setting between $+10$ and -10 kV in steps of $\sim$ 1 kV. With each voltage setting, we took a scan of beam profiles in both horizontal and vertical planes using wire monitor WS061. The voltage span produces a phase advance larger than 90°, allowing the measured projections to be informative enough for a complete reconstruction of the phase space, even if it is of irregular shape such as a filamented S-shape.

Test on Known Model

We first tested the MENT program on an artificially generated S-shaped phase space, with intention to mimic the actual measurements of 23 profiles. Using the transfer matrices calculated from Q111 to WS061, we transformed this S-shaped phase space and then projected it onto x-axis to find the distributions. This is illustrated in Fig. 2. These

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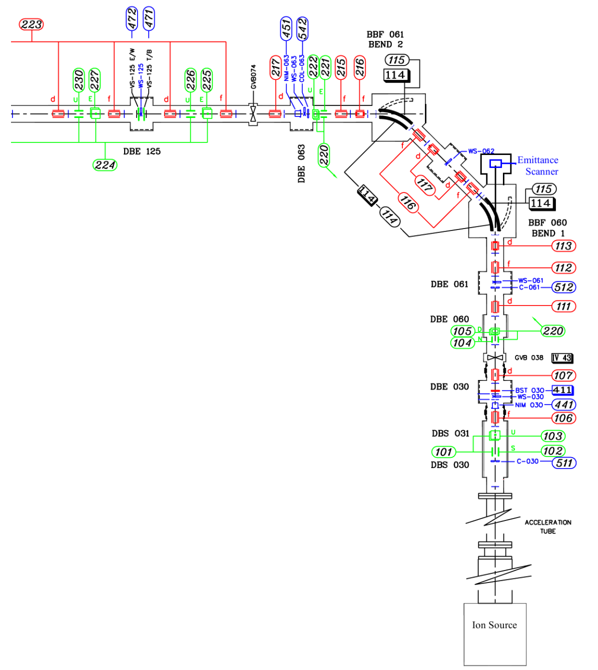

Figure 1: Diagram of TRIUMF 300 keV H^- injection beamline front end, where the measurements were performed.

projections, along with the corresponding transfer matrices, were fed into the MENT program for iterative computation to reconstruct the 2-D phase space. As compared in Fig. 3, the MENT program reproduced not only the details of the filaments, but also accurately revealed the rms value of emittance to better than 1%.

Scanning Wire Measurements

Since we were especially interested in any filaments and/or distortions in the phase space, it was important to maximize the signal-to-noise ratio of the profiles measured. The noise level that we cut off was typically 0.4% of the maximum signal level.

Fig. 4 shows the resulting tomography in both planes. Fig. 5 shows the measured profiles, along with the MENT reconstructed ones. All the profiles are well reproduced.

EMITTANCE SCANNER MEASUREMENTS

We have an Allison-type emittance scanner installed in the same section of the beamline but at $\sim$ 1.3 m down-

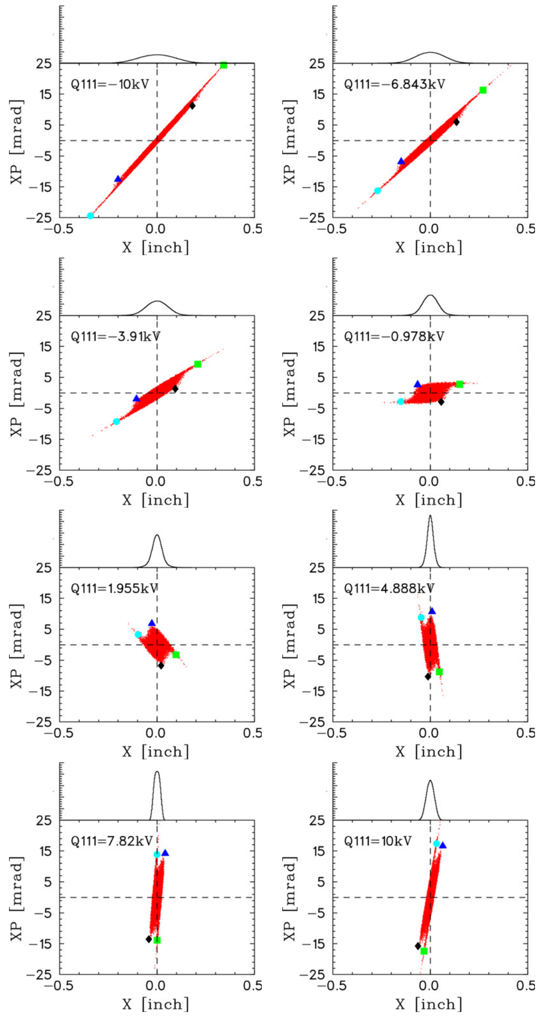

Figure 2: Transformation of an originally S-shaped phase space under various settings of the quadrupole, and its projection on the x-axis. 4 of the particles are given special symbols so that one can clearly see the phase advance.

stream of Q111 (see Fig. 1). This gives a direct measurement of emittances in both planes. In order to make a close comparison with the MENT result, we needed to transform the measured phase plots backwards to the Q111 entrance, the same position as the tomography reconstruction. The transformation we used is linear, including the linear space charge force. See Fig. 6.

Comparing Fig. 4 and Fig. 6, we see that the beam halos are quite different. To address whether the difference was due to nonlinear space charge force, we used the code TRACK[3] to make a multi-particle simulation. Our measurements were taken with a beam current of 580 μA DC, where the space charge has an effect but does not dominate. A number of macro particles were launched at the emittance measurement device, following the 2-D density distribution as given in Fig. 6. These particles were then tracked backwards through 2 electrostatic quads up to the Q111 entrance. By varying the space charge neutralization level between zero and 100% (it was known to be near

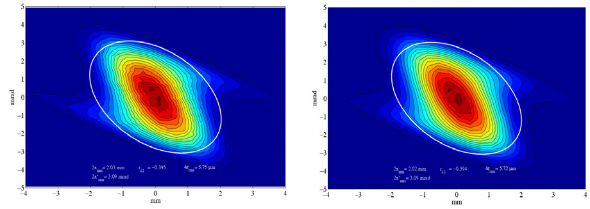

Figure 3: Comparison of the original S-shaped phase space (left) with the MENT reconstructed one (right). The shape of the filaments is evidently reproduced, and also the emittance value is accurately revealed. The white contour is the 2rms ellipse.

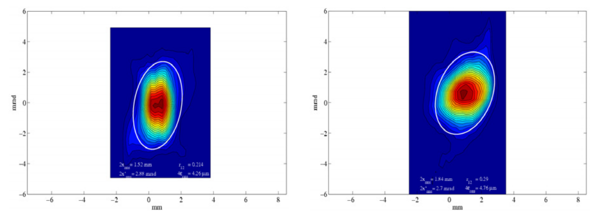

Figure 4: Phase space tomography reconstructed from a series of 1-D profiles measured at WS061. Left: horizontal plane. Right: vertical plane.

zero, as expected for a beamline with electrostatic lenses), we obtained various results, but none of these show good agreement with the MENT tomography. As an example, see Fig. 7 for the result of zero neutralization.

DISCUSSION

The tests on known model convinced that the MENT can nicely reproduce the beam phase space including the halos. But with the measured data, we got rather different halo pictures between the MENT tomography and the emittance scanner, and this discrepancy seems to be hardly explainable with particle's space charge interactions. Further investigations are planned.

ACKNOWLEDGEMENT

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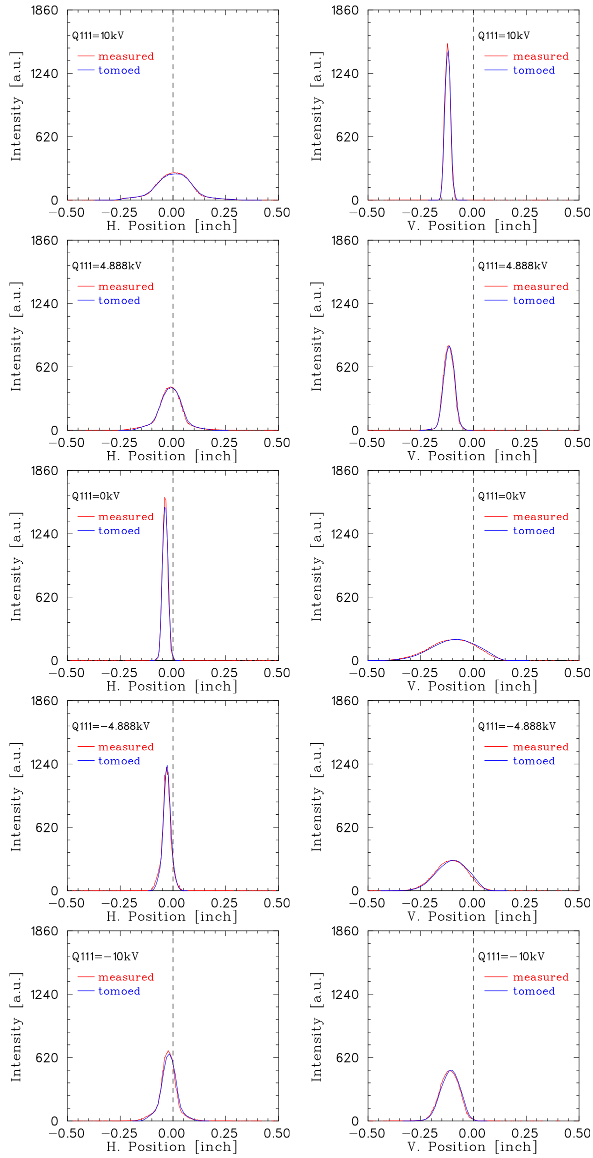

Figure 5: Comparison between the profiles measured and the projections reconstructed from the MENT, at various settings of Q111.

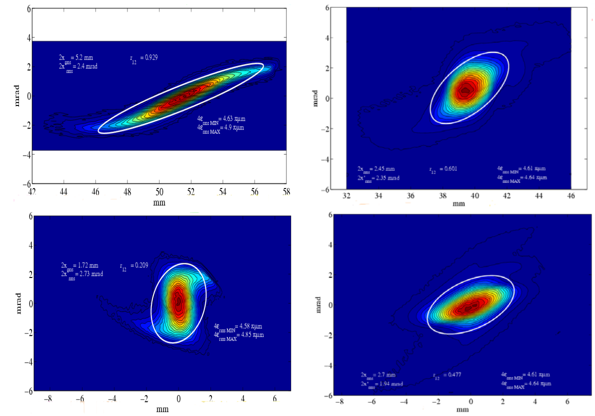

Figure 6: Top: Emittances measured at the Allison-type scanner. Bottom: Emittances determined by linear transformation from the scanner backwards to the quad Q111 entrance. Left: horizontal. Right: vertical. Note that all phase space plots have been drawn with the same scale as Fig. 4.

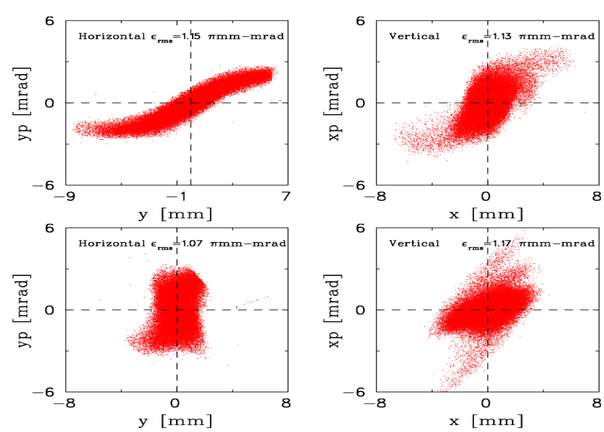

Figure 7: Result of multi-particle tracking simulation with space charge. Top: starting at the emittance scanner. Bottom: tracked backward to Q111 entrance.