Pepperpot development for TAMUTRAP and He6CRES

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Using the cyclotron radiation emission spectroscopy (CRES) technique developed by the Project-8 collaboration [1], the ^{6}HeCRES experiment plans to measure the β-spectrum of ^{6}He, ^{14}O, and ^{19}Ne. This is done by allowing the atoms to decay within a small waveguide that will propagate the cyclotron radiation emitted from the beta. Future iterations of the experiment plan to use an ion beam and trap the ions of interest within a Penning trap that is also a waveguide. Due to the constraint of radial confinement within the waveguide, precise control of the position and divergence of the beam as it enters the trap is required. The position-momentum phase space of the beam is called the emittance, and can be measured using a pepper-pot. Following Liouville's theorem, the emittance remains constant in time barring non-conservative forces [2]. Employing a radiofrequency quadrupole Paul trap (RFQ) we are able to cool and bunch the beam lowering the emittance, the extent of which can be tested with a pepper-pot.

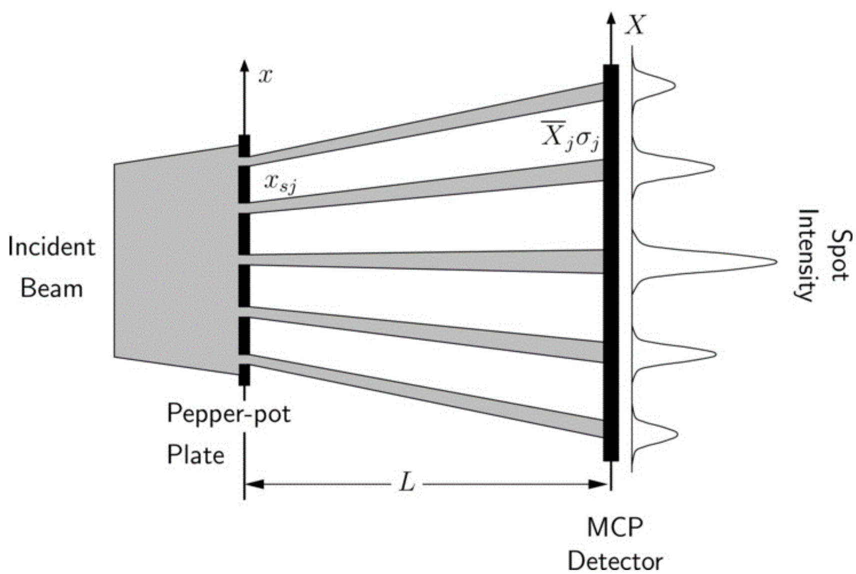

Fig. 1. Example of a typical emittance measurement [3].

The analysis of the pepper-pot is non-trivial and requires precise knowledge of the pepper-pot mask applied before the detector and the distance to the detector. With knowledge of the holes on the mask, as well as their image on the detector one can compute the rms emittance in one direction from the observables shown in Fig. 1, according to:

$$\varepsilon_x = \sqrt{\langle x^2\rangle\langle x'^2\rangle - \langle xx'\rangle^2}$$

$$\varepsilon_x = \frac{1}{N}\sqrt{\left[\sum_{j=1}^{p} n_j\left(x_{sj}-\bar{x}\right)^2\right]\left[\sum_{j=1}^{p}\left[\frac{n_j\sigma_j^2}{L^2}+n_j\left(\overline{x_j'}-\overline{x'}\right)^2\right]\right]-\left[-N\bar{x}\overline{x'}\sum_{j=1}^{p} n_j x_{sj}\,\overline{x_j'}\right]^2}\ .$$

where N is the total intensity of the beam on the detector, n_j is the intensity of beamlet j, x_{sj} is the position of the j^{th} hole in the mask, $\bar{x}$ is the mean position of the beam on the detector, σ_j is the standard deviation of the j^{th} beamspot, and L is the distance between mask and detector. The divergence of the beam $\overline{x_j'}$ is given by the following:

$$\overline{x_j'} = \frac{\overline{X_j} - x_{sj}}{L},$$

where $\overline{X_j}$ is the mean position of the j^{th} spot on the screen. This process can be completed in both transverse directions and the reported emittance is then the average of the two.

An analysis software named Pypperpot has been written in the python programming language [4] to read images of a pepperpot emittance measurement and return the emittance of the beam as well as the phase space profile. The software has been tested with simulated pepperpot experiments of various beam and mask conditions to maximize understanding before upcoming measurements on the TAMUTRAP beamline. After successful testing, the constructed pepperpot, and Pypperpot will be a useful tool for understanding beam profiles wherever applied, not only for TAMUTRAP and CRES, but also the He-LIG and LSTAR upgrades and throughout the Cyclotron Institute.

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