Pypperpot simulation and analysis software for beam diagnostics

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Following it's inception last year as a simple code [1], Pypperpot has evolved into a user friendly software created to aid in the design and analysis of pepper-pots, a powerful beam diagnostic tool. The area of the position-momentum phase space of the beam is called the emittance, and can be measured using a pepper-pot. Following Liouville's theorem, barring non-conservative forces, the emittance of a beam will remain constant [2]. Though the space-charge effect is non-conservative, the effect is minimal across short distances. Because of this, a compact pepper-pot system must be created and deployed at target sites, but due to the energy dependent efficiency of a given pepper-pot mask, each mask has a range of emittances it is sensitive to. Therefore, the simulation portion of Pypperpot allows for beam generation, as shown in Fig. 1, as well as trajectory calculations through a designed mask to test the acceptance range of a mask before manufacturing. Generated beams can be saved for testing through multiple masks, and trajectories can be saved as images for analysis.

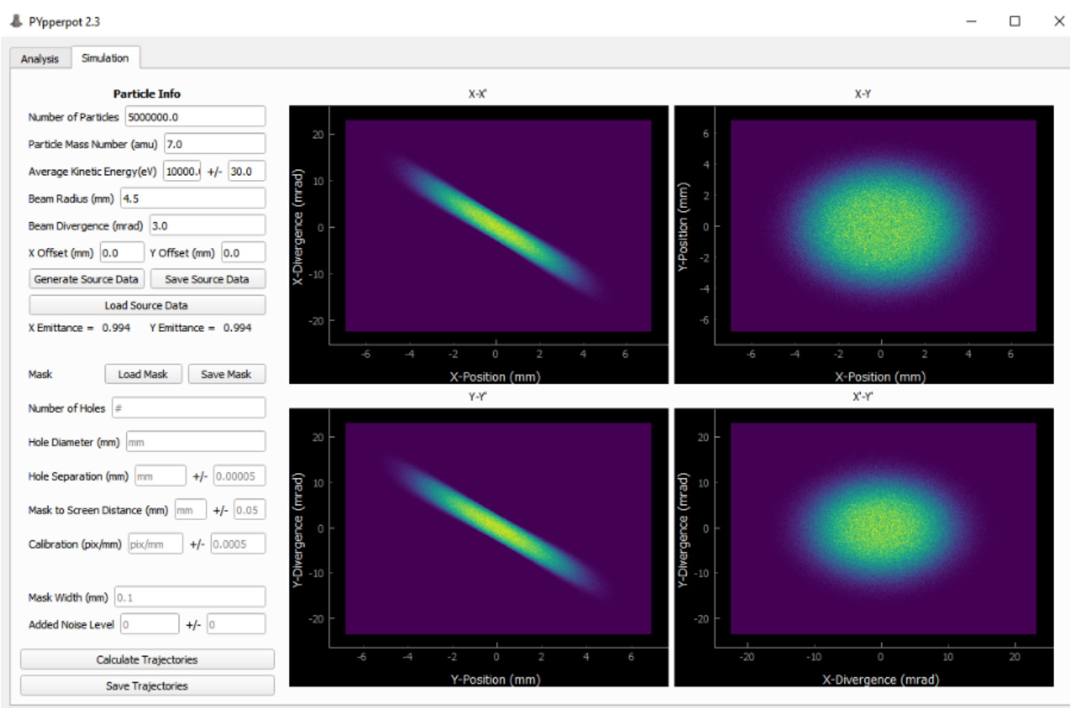

FIG. 1. Pypperpot's simulation tab showing a simulated beam depicting the X-Y phase space

Following the simulation, there is a separate analysis tab that reads in pepper-pot data as images or matrices. When information from the mask is supplied, the user has the ability to tune the algorithm that senses the peaks in the image to make sure their data is accurately fit. The data is then fit peak by peak and the phase space for the beam is displayed along with the measured emittance as shown in Fig. 2. Because the emittance formula was originally derived for a slit mask and extended to the pepper-pot the formula was for measuring projections as either row or column of the mask [3]. To make Pypperpot holenumber agnostic, the peak-by-peak fit was preferred, and required the disentangling of each peak from the projection, as done in [4], in the equations for emittance. With a simulated mask recently found to be sensitive to the region of requirement for both the Light-ion guide Separator for Texas A&M's Rare isotope beams (LSTAR) [5] and the Gas Operated Large Ion-bunch Atomic Trap for He6CRES (GOLIATH), tests of the emittance on these beamlines using Pypperpot will hopefully be conducted soon.

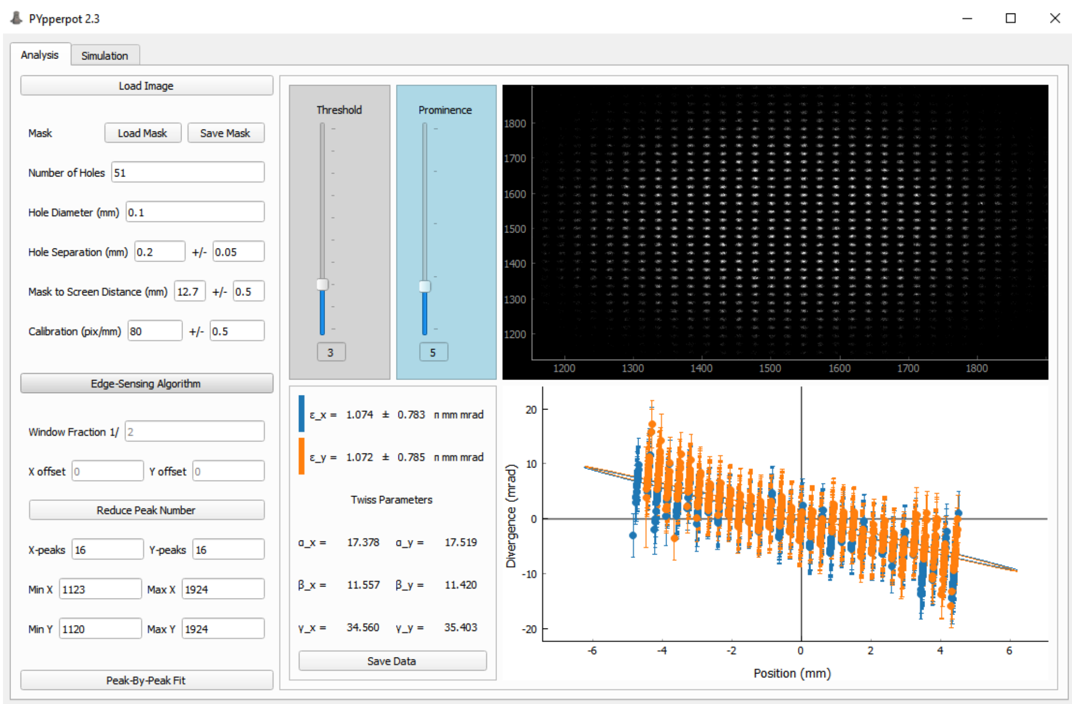

FIG. 2. Pypperpot's Analysis tab depicting a pepperpot image and the resulting emittance and phase space

[1] D. McClain *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2022-2023), p.IV-37.

[2] J.W. Gibbs, Proceedings of the American Association for the Advancement of Science. (1848).

[3] M. Zhang, No. FNAL-TM-1988. Fermi National Accelerator Lab.(FNAL), Batavia, IL, United States (1996).

[4] K. Pearson, Philosophical Transactions of the Royal Society of London. (A.) **185**, 71 (1894).

[5] D. Melconian *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2021-2022), p. IV-61.