

# Marshall Space Flight Center's Solar Wind Facility

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## I. Introduction

Historically, NASA's Marshall Space Flight Center (MSFC) has operated a Solar Wind Facility (SWF) to provide long term particle and photon exposure to material samples. The requirements on the particle beam details were not stringent as the cumulative fluence level is the test goal. Motivated by development of the faraday cup instrument on the NASA Solar Probe Plus (SPP) mission, the MSFC SWF has been upgraded to include high fidelity particle beams providing broadbeam ions, broadbeam electrons, and narrow beam protons or ions, which cover a wide dynamic range of solar wind velocity and flux conditions. The large vacuum chamber with integrated cryo-shroud, combined with a 3-axis positioning system, provides an excellent platform for sensor development and qualification. This short paper provides some details of the SWF charged particle beams characteristics in the context of the Solar Probe Plus program requirements. Data will be presented on the flux and energy ranges as well as beam stability.

## II. Solar Wind Facility – General Description

The external layout of the SWF is shown in Fig. 1. The SWF chamber has internal dimensions of 2.72 m long by 1.23 m inner diameter with high-vacuum pumping capability that is capable of a base pressure in the low  $10^{-7}$  Torr range. Access to the chamber is through a removable door on the east end of the chamber. The door contains several ports oriented such that their axes converge to a location  $\sim 110$  cm from the door-chamber interface. The port arrangement allows use of various combinations of particle and photon sources along with video cameras as required.

The chamber is surrounded by two pairs of Helmholtz Coils. The coil pair that controls the horizontal north-south magnetic field component are octagon shaped with semi-major axes at 3.35 m with 9 turns of 12-gauge wire each. The coil pair that controls the vertical magnetic field component are square shaped at 1.83 m per side with 8 turns of 12-gauge each. Both sets of coils are independently computer controlled for wire current.

The chamber has a two-dimensional linear stage system coupled with a rotational stage that allows a test article to be positioned and rotated within the focal plane. The stage configuration for testing the Solar Probe Cup (SPC) instrument (Kasper et al., 2016) of the NASA Solar Probe Plus mission is shown in Fig. 2. The X- and Z- motion translation stages move at 4000 steps/inch. The rotation stage moves at 40 steps/degree. Motion for each stage is computer controlled.

### III. Broadbeam Ion Source

The broadbeam ion source is a modified Kaufman-type and is mounted to align with the SWF chamber axis. The source was modified by replacing the original grid set with two 8-cm diameter, defocused, matched Molybdenum grids. Fig. 3 shows both internal and external views of the source. The ion source housing is electrically isolated from the chamber and its potential is independently controlled. The beam energy is basically the sum of anode voltage and the housing bias potential.

Fig. 4 shows the flux versus energy performance curves as a function of gas flow to the source. For SPC testing, the requirement on beam energy spread is  $\Delta E/E \leq 3\%$ . With the exception of the 0 sccm points, all points on the graph in Fig. 3 meet the energy spread criteria. Other flow rates are possible, but the energy spread increases above 3%. Beam uniformity varies over an 80 mm diameter from  $> 90\%$  for 140 eV to  $\sim 80\%$  at 8100 eV. Beam energy and flow rate are each computer controlled. Beam measurements were obtained by a 4-grid, single collector Retarding Potential Analyzer (RPA-1) operated in the DC mode.

Stability of the freestream ion beam was measured in two ways: high time resolution of the RPA-1 current and by AC operation of a second, 6-grid instrument (called RPA-2). Fig. 5 shows the results of RPA-2 operation at the frequency of 1171.875 Hz for a continuous 5-minute data acquisition. This is the planned flight AC operating frequency of the SPC. The well-defined shape of the instrument response indicates beam stability at this key frequency. What noise that is observed is attributed to less than optimum design for RPA-2; i.e., more ground grids are needed to capacitively decouple the collector from the modulator grid.

### IV. Broadbeam Electron Source

The broadbeam electron source is mounted on the north bellyband port of the SWF chamber door. It consists of two independent filaments mounted on a Macor plate surrounded by a grounded anode. Only one filament is used at a time and is biased to the beam energy. Fig. 6 shows external views of the electron source.

Fig. 7 shows the flux versus energy performance curves as a function of cathode current. The energy spread requirement of  $\Delta E/E \leq 3\%$  is met by all points within the flux range boundary with the exception of energies  $< 100$  eV. For those energies between 90 eV and 100 eV, the  $\Delta E/E$  value is only slightly larger than 3%. Beam uniformity varies over a 80 mm diameter from  $> 90\%$  for 90 eV to  $\sim 80\%$  at 2100 eV. The coil current for the vertical magnetic field component is adjusted in concert with energy changes between 90 eV to 1500 eV. The coil current for the horizontal magnetic field component remains fixed at all energies. The beam energy, cathode current, and Helmholtz coil currents are each computer controlled.

Fig. 8 shows a 5-minute data acquisition for AC operation of RPA-2. The well-defined shape of the instrument response indicates beam stability at the 1171.875 Hz frequency.

## V. Pencil Beam – Ions

The source for the ions in the pencil beam is a water cooled Duo-plasmatron source. This source can be used with either hydrogen or argon gas feed. The beam line has both steering and focusing electrodes. The beam line is mounted on the south bellyband port of the SWF chamber door. To create the narrow diameter ion beam, a 1mm pin-hole aperture plate is installed in the chamber normal to the beam axis. This orientation is achieved by a 20 degree rotation of the translation-rotation stage system setup. The beam energy is computer controlled.

Fig. 9 shows a picture of the setup. RPA-1, with its 12.5 mm aperture, was used to measure the beam downstream from the pinhole. For energies  $> 1000$  eV, basically no divergence from the pinhole is observed. The utility of the fixed position pencil beam is to maneuver the SPC so that each of the four collector segments can be exposed one at a time.

## VI. Summary

MSFC's Solar Wind Facility has been upgraded from its historical capability that included long term, high fluence material exposures. The new capability includes high fidelity particle beams for space flight instrument calibration. The capability also exists to add solar photon radiation if required. Both broadbeam ion and electron beams have flux control over several orders of magnitude. Computer control allows either energy and flux scans with user control of start value, stop value, step size, and dwell time per step.

## Acknowledgments

Support for the SWF upgrade is acknowledged from the SWEAP investigation on SPP, J. C. Kasper (U. Michigan) Principal Investigator. A. C. Case (Harvard Smithsonian Astrophysical Observatory) provided the Python software for AC operation of RPA-2. Students A. Gagnon and L. Redmond for their help in assembly and checkout of the RPA-2. K. Wright acknowledges current support from MSFC-USRA contract NNM13AA43C and previous support from MSFC-University of Alabama-Huntsville (UAH) Cooperative Agreement NNM11AA01A. P. Whittlesey acknowledges previous support from MSFC-UAH Cooperative Agreement NNM11AA01A. The SWF is operated under management of the NASA/MSFC Non-Metallic Materials and Space Environmental Effects Branch.

## References

- J. C. Kasper, et al., Solar Wind Electrons Alphas and Protons (SWEAP) Investigation: Design of the solar wind and coronal plasma instrument suite for Solar Probe Plus, *Space Sci. Reviews*, 29 October 2015, DOI 10.1007/s11214-015-0206-3.

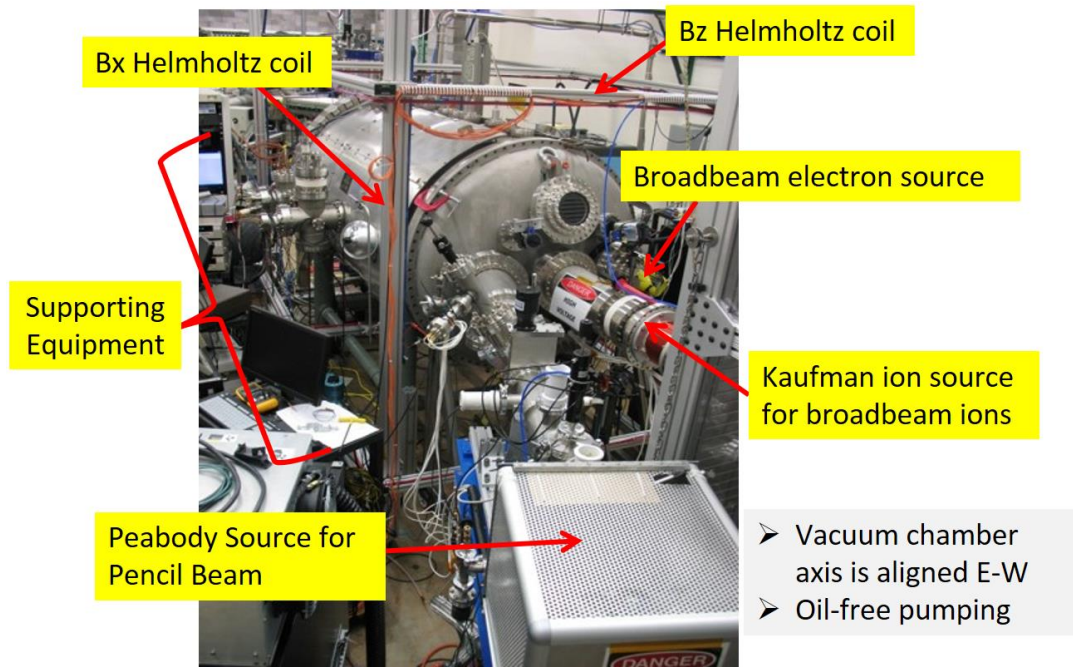


Fig. 1. MSFC Solar Wind Facility layout. Supporting equipment includes computers, power supplies, electrometers, etc.

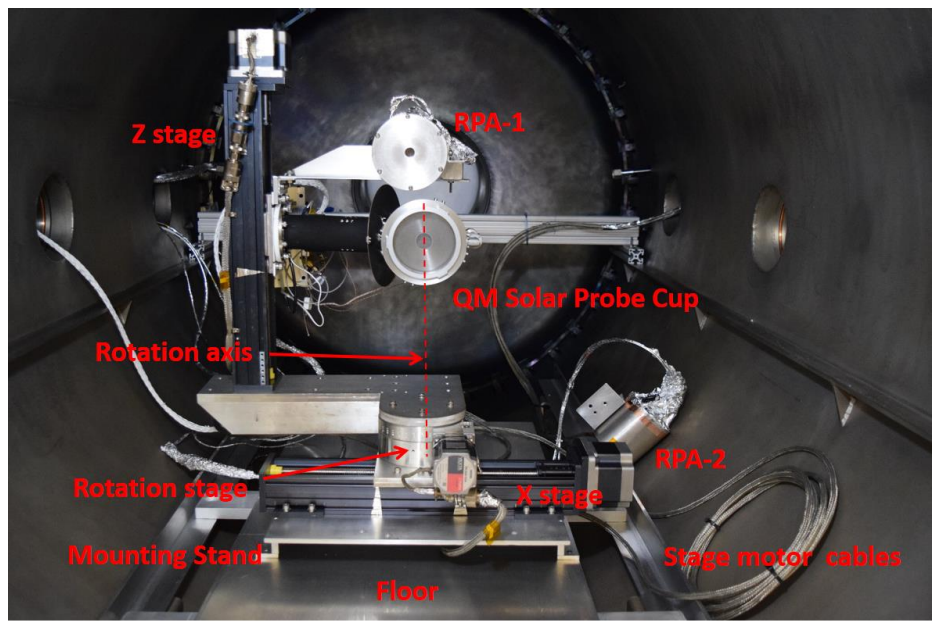


Fig. 2. Internal view of SWF showing the stage arrangement for testing the Qualification Model (QM) Solar Probe Cup.

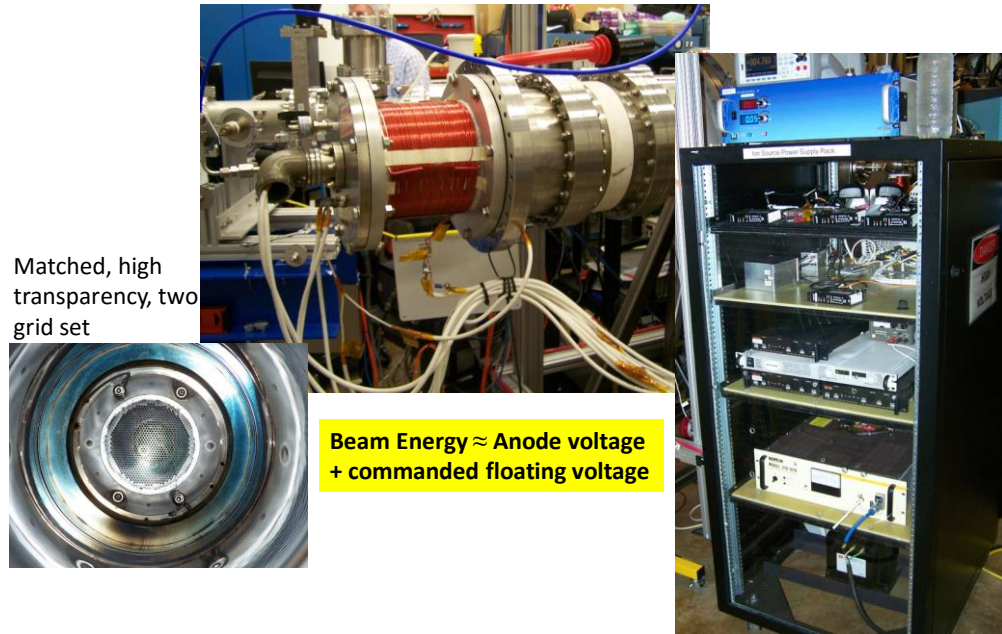


Fig. 3. Modified Kaufman ion source: external view, internal view of grids, and dedicated electrical equipment rack.

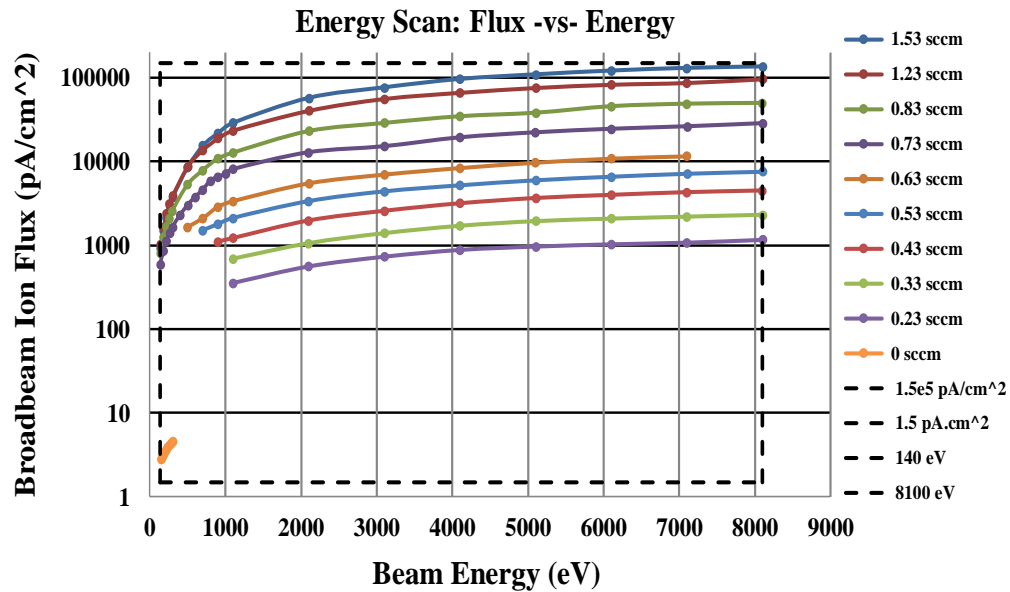


Fig. 4. Performance curves (beam flux versus beam energy) for the modified Kaufman ion source as a function of argon gas flow rate.

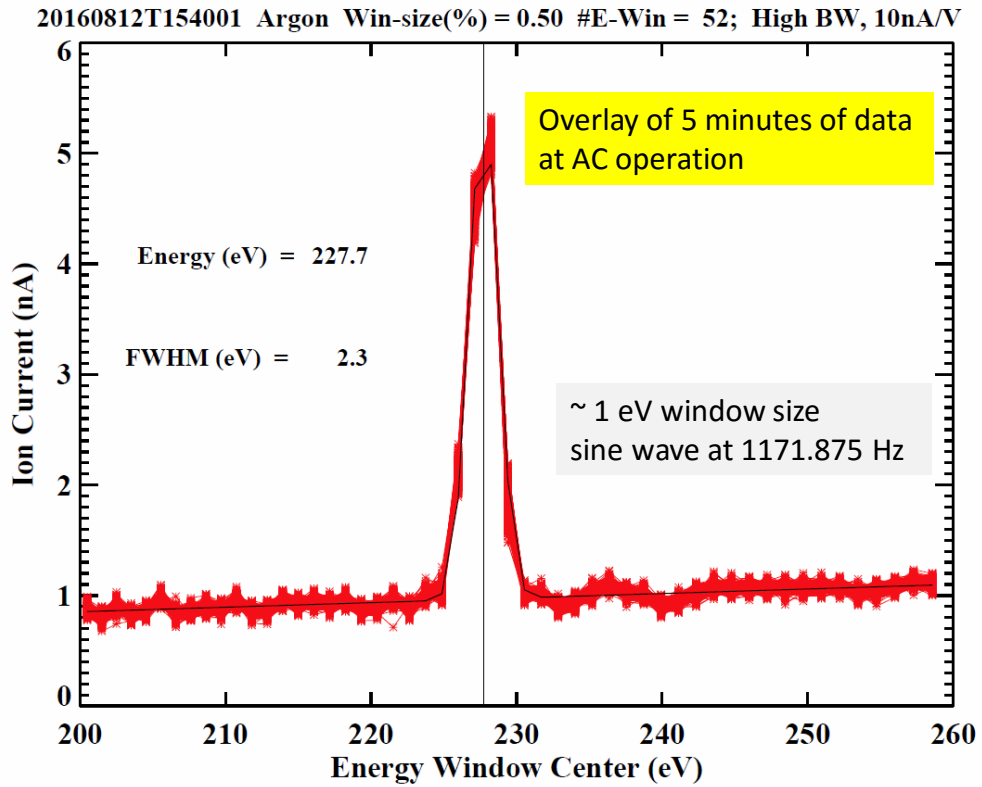


Fig. 5. Current versus energy for AC operation of RPA-2 at single  $\text{Ar}^+$  beam energy.

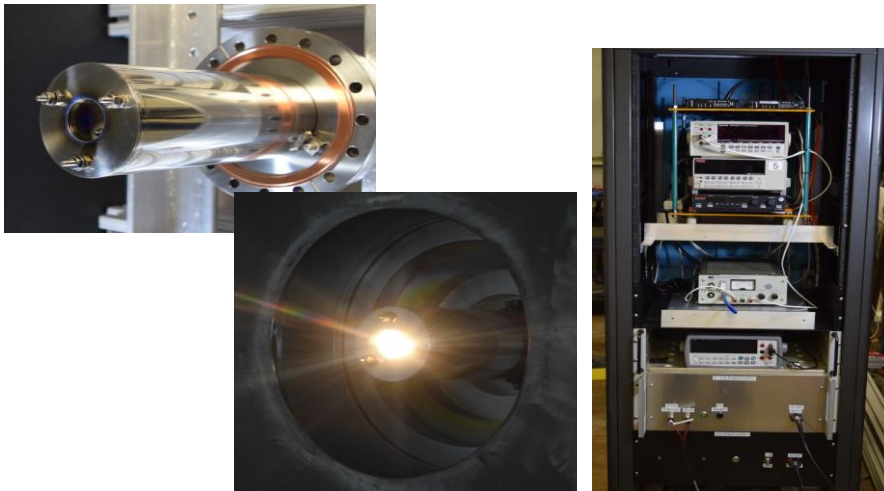


Fig. 6. View of electron source and dedicated electrical equipment rack.

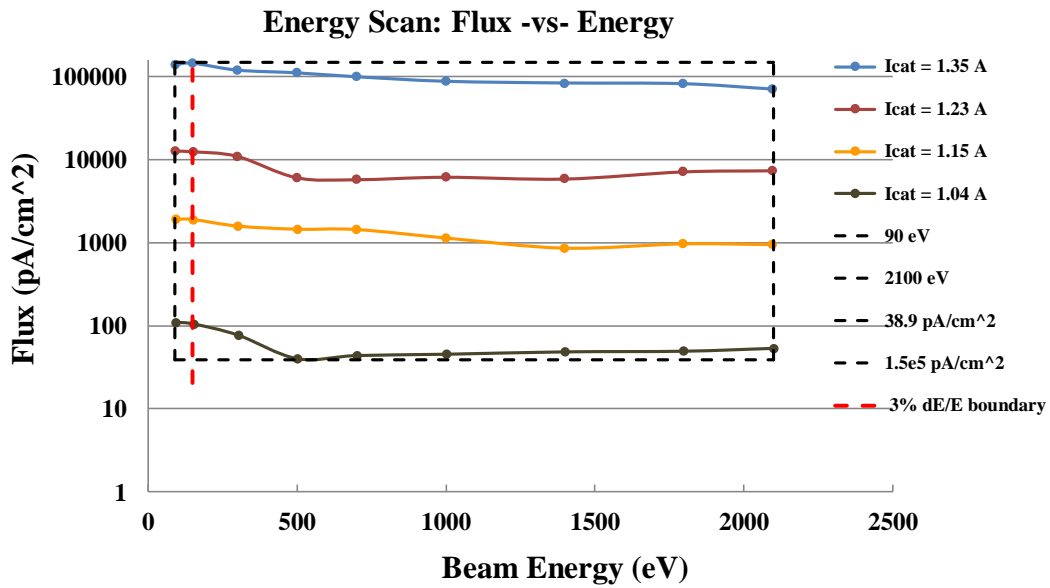


Fig. 7. Performance curves (beam flux versus beam energy) for the electron source as a function of cathode current.

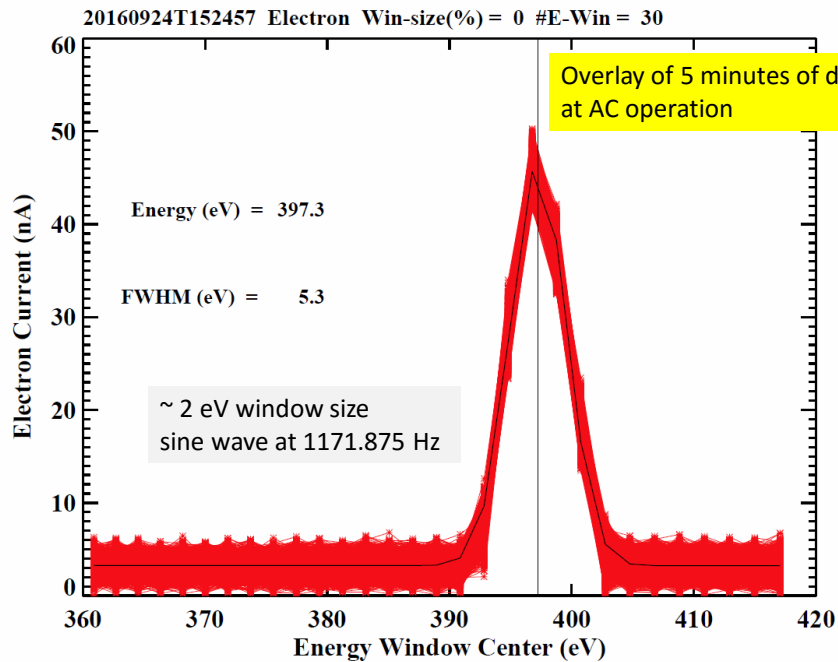


Fig. 8. Current versus energy for AC operation of RPA-2 at single electron beam energy.

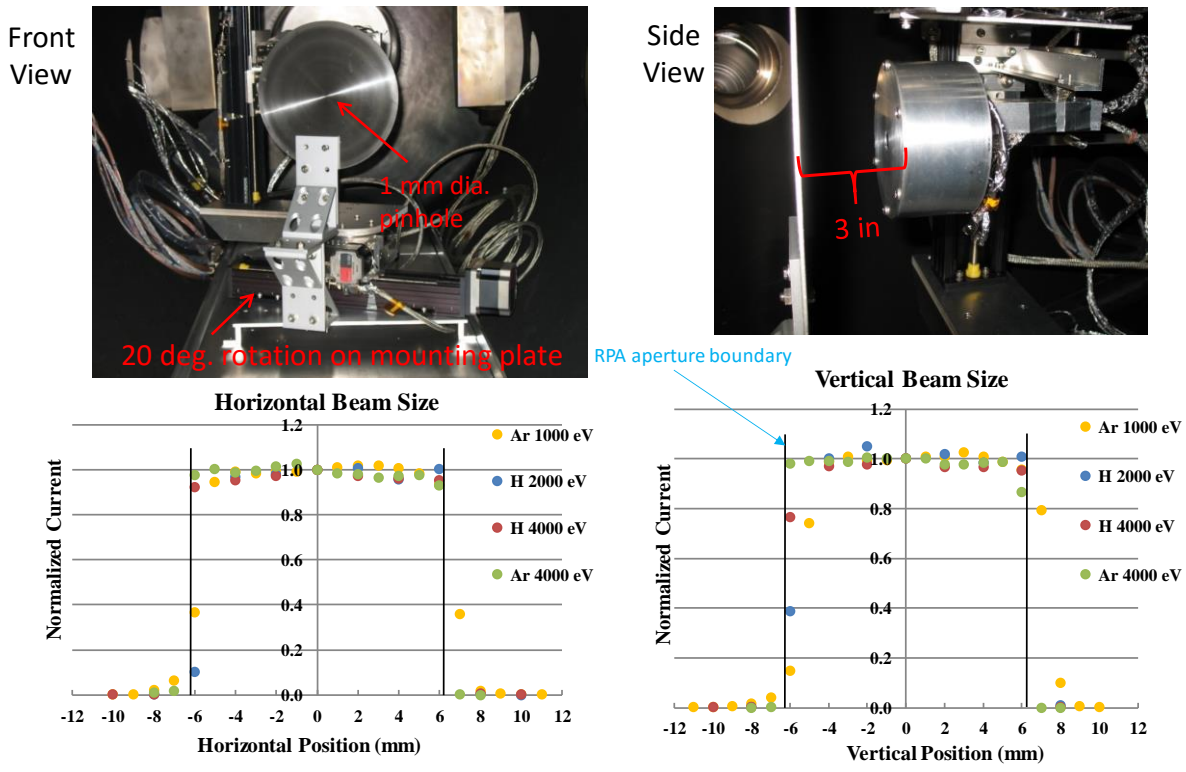


Fig. 9. View of internal SWF configuration for pencil beam setup. Minimal or no beam divergence beyond the 1 mm diameter pinhole is observed.