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Measurement of the Energy Spread for CeC Project

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The Coherent Electron Cooling [1] requires small energy spread and uniformity of energy along the bunch [2]. The diagnostics line is utilized for the measurement of the electron beam parameters. The beamline layout is shown in Fig. 1. Three quadrupoles after the linac are used to match beam into the common section. The main dipole is used to deflect beam towards common section. If it is switched off the beam goes to the diagnostics line. The beam optics in the diagnostics line is controlled by four quadrupoles. The deflecting cavity [3] sweeping beam in the vertical direction follows the quadrupoles. Sector dipole is used for energy parameters measurement. It has deflection angle of 30 degrees. With diagnostics dipole switched off the beam propagated to the insertable slits system for emittance measurement. There are four profile monitors in the line, The first profile monitor (ACC YAG) is after the main dipole. The second profile monitor (YAG3) is in front of the diagnostics dipole after the deflecting cavity. YAG1 profile monitor is placed after the slits, and YAG2 profile monitor is placed after the diagnostics dipole. There is a solenoid between the deflecting cavity and YAG3. It is used for the beam energy measurement.

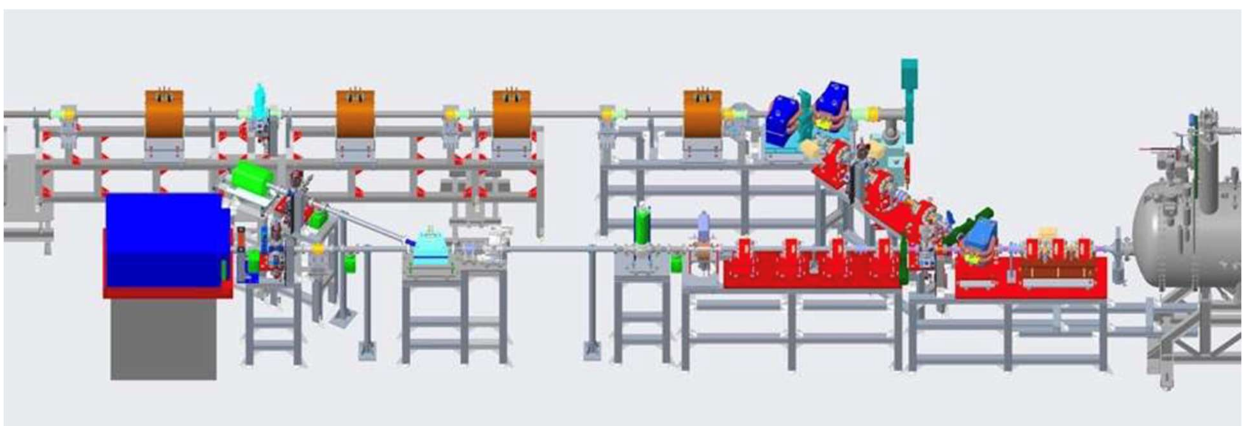

Figure 1: Layout of the CeC diagnostics line.

The energy spread can be measured from the horizontal beam width at the location with known dispersion and the YAG2 profile monitor serves this purpose. The value of the dispersion at the profile monitor can be found from the distance from the profile monitor to the axis of the straight beamline going to the TAG1 profile monitor (based on assumption that there is no dispersion prior the diagnostics beamline. This value is 0.87 meters. The dispersion can be verified by changing the dipole current or the linac voltage. These measurements can be affected by the magnet hysteresis or beam steering by the linac. Therefore, they were not used.

The beam size is also affected by the beam emittance. The beam functions can be measured with quadrupole scan, but we need to know the transport matrix from the quadrupole to the YAG2 profile monitor. The layout for the transport matrix calculations is shown in Fig. 2.

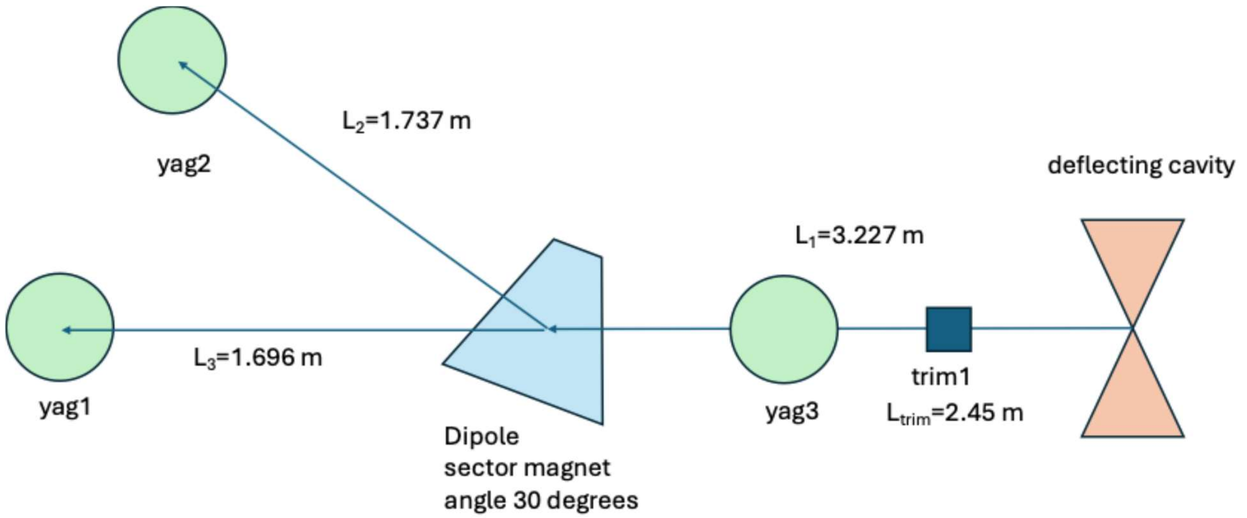

Figure 2: The schematical layout of the diagnostics line used for the transport matrix calculations. Distance form the last quadrupole Q4 to the diagnostics dipole is 3.697 meters. Distance from the trim to the dipole is 2.45 meters.

The measurements for the transport matrix were performed using trims 1 located between the deflecting cavity and solenoid using the electron beam at the full energy of 10 MeV (γ=19.57). The trims were calibrated by measuring the displacement on the YAG1 profile monitor with the dipole switched off. Then, the dipole nominal current of 95.0 A (B_{peak}=0.784 kGs) was set to deflect beam to the center of the YAG2 profile monitor. The horizontal M_H and vertical M_V transport matrices were evaluated as for the sector magnet with weak edge focusing surrounded by to two drift spaces.

$$M_v = \begin{bmatrix} 1 & L_b \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 1/f & 1 \end{bmatrix} \begin{bmatrix} 1 & \rho\theta \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 1/f & 1 \end{bmatrix} \begin{bmatrix} 1 & L_a \\ 0 & 1 \end{bmatrix}$$

$$M_H = \begin{bmatrix} 1 & L_b \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ -1/f & 1 \end{bmatrix} \begin{bmatrix} \cos\theta & \rho\sin\theta \\ -\dfrac{\sin\theta}{\rho} & \cos\theta \end{bmatrix} \begin{bmatrix} 1 & 0 \\ -1/f & 1 \end{bmatrix} \begin{bmatrix} 1 & L_a \\ 0 & 1 \end{bmatrix}$$

Trim 1 induced motion on the YAG2 profile monitor equal to 20.2 mm/A in the vertical plane and -3.42 mm/A in the horizontal plane. The found value for edge focusing is f=12.06 meters, and for the effective radius of curvature is ρ=46.4 cm.

To receive the good resolution, the beam should be tightly focused. For this purpose, we need to have the beam size large in the focusing element. Therefore, the triplet quadrupoles are set zero to let the beam to expand. The image of the beam on the YAG3 profile monitor with diagnostics quadrupoles at zero is shown in Fig. 3.

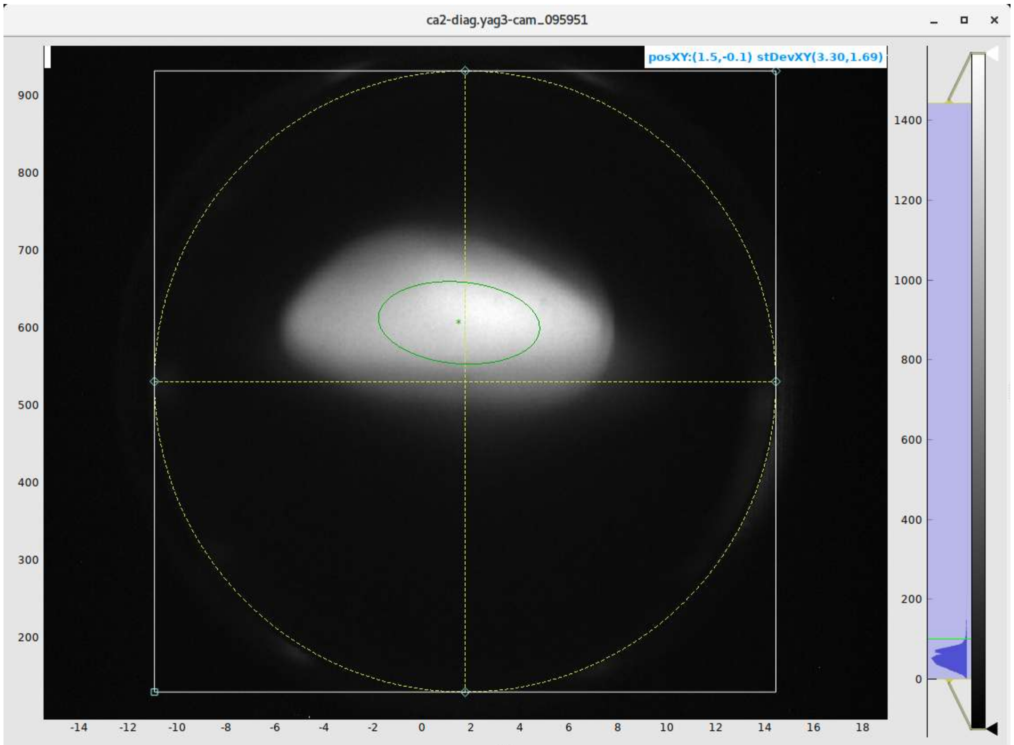

Figure 3: Image of the electron beam on the YAG3 profile monitor with triplet solenoids switched off.

Next step is to phase the deflecting cavity. During this measurement the electron beam is tightly focused on the YAG3 profile monitor as shown in Fig. 4. The focusing can be done in two configurations. In the first the Q3 quadrupole is focusing and the Q4 quadrupole is defocusing. Such arrangement provides for the smallest vertical beam size on the YAG3 profile monitors and is used for the bunch current profile measurement. For the measurements described below we need to minimize the horizontal beam size, and the Q3 quadrupole is defocusing and the Q4 quadrupole is focusing. This configuration also ensures small vertical beam size in the deflecting cavity, to minimize the beam energy spread induced by the deflecting cavity.

We also center beam on the Q4 quadrupole using the main dipole trim in the horizontal plane and the last vertical trim in the triplet area. After the quadrupole centering the beam is steered to the center of the YAG3 profile monitor with the help of the trims TV1 and TH1 place between the deflecting cavity and the solenoid.

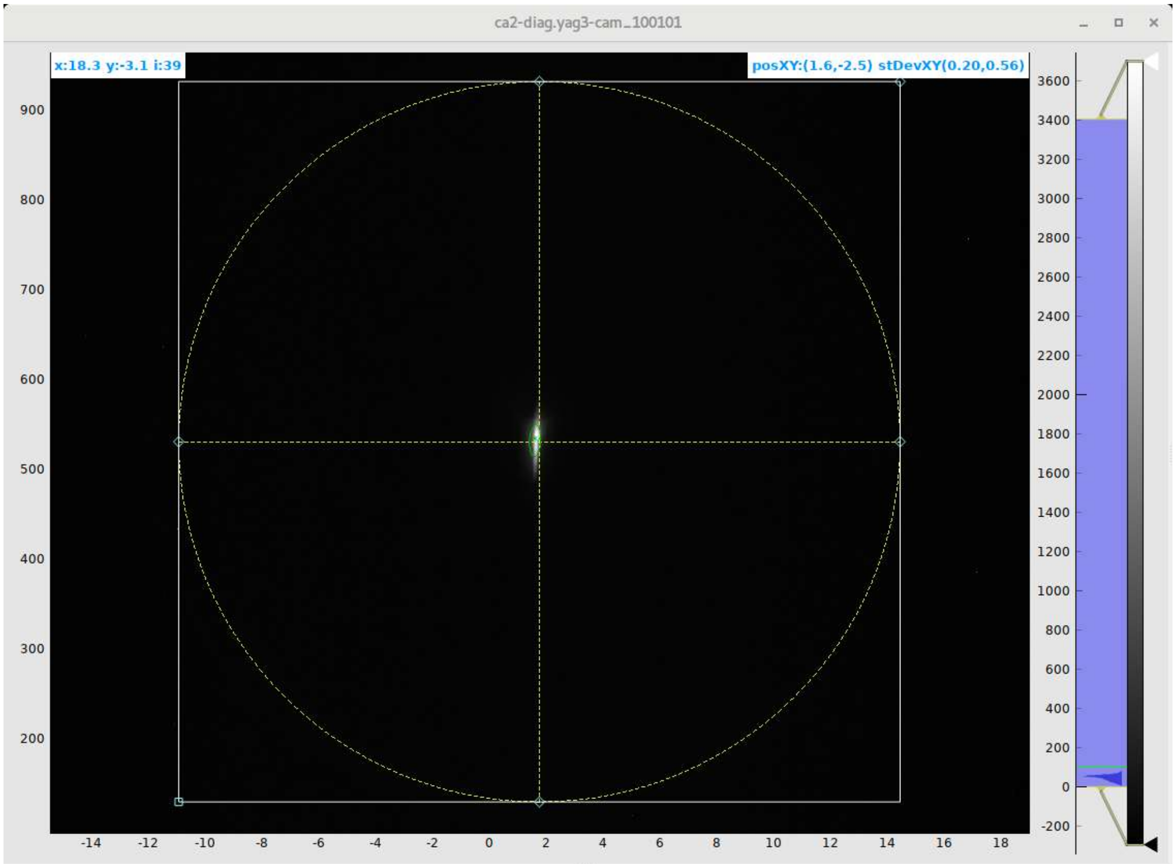

Figure 4: The image of the tightly focused beam on the YAG3 profile monitor. The Q3 quadrupole is defocusing and the Q4 quadrupole is focusing. I such configuration vertical beam size on YAG3 (0.56 mm) is larger than horizontal (0.20 mm).

The results of the deflecting cavity measurements are shown in Fig. 5. From the measurements the zero-crossing phase is established, and amplitude of the displacement serves as measurement of the deflecting cavity voltage. The kick on the YAG2 profile monitor is calculated using earlier found transport matrix.

The next step is set the defecting cavity phase to the zero-crossing value and measure the beam parameters for the central slice. The deflecting cavity voltage is set to have reasonable (few mm r.m.s.) vertical size on the YAG3 profile monitor. The region of interest is modified to a narrow horizontal band and the quadrupole Q4 is scanned while the current in the Q3 is maintained at the level required beam to be focused on YAG2 profile monitor. The dependence of the r.m.s. horizontal width of the central part of the electron bunch on the quadrupole strength is used to calculate the emittance and β-function of the central slice. Since, the quadrupole is centered there is no substantial beam steering. The vertical beam size is also not changed significantly during the scan. Both factors are important to avoid mixing of the adjacent slices. The scan can be used for the measurement of the other slices.

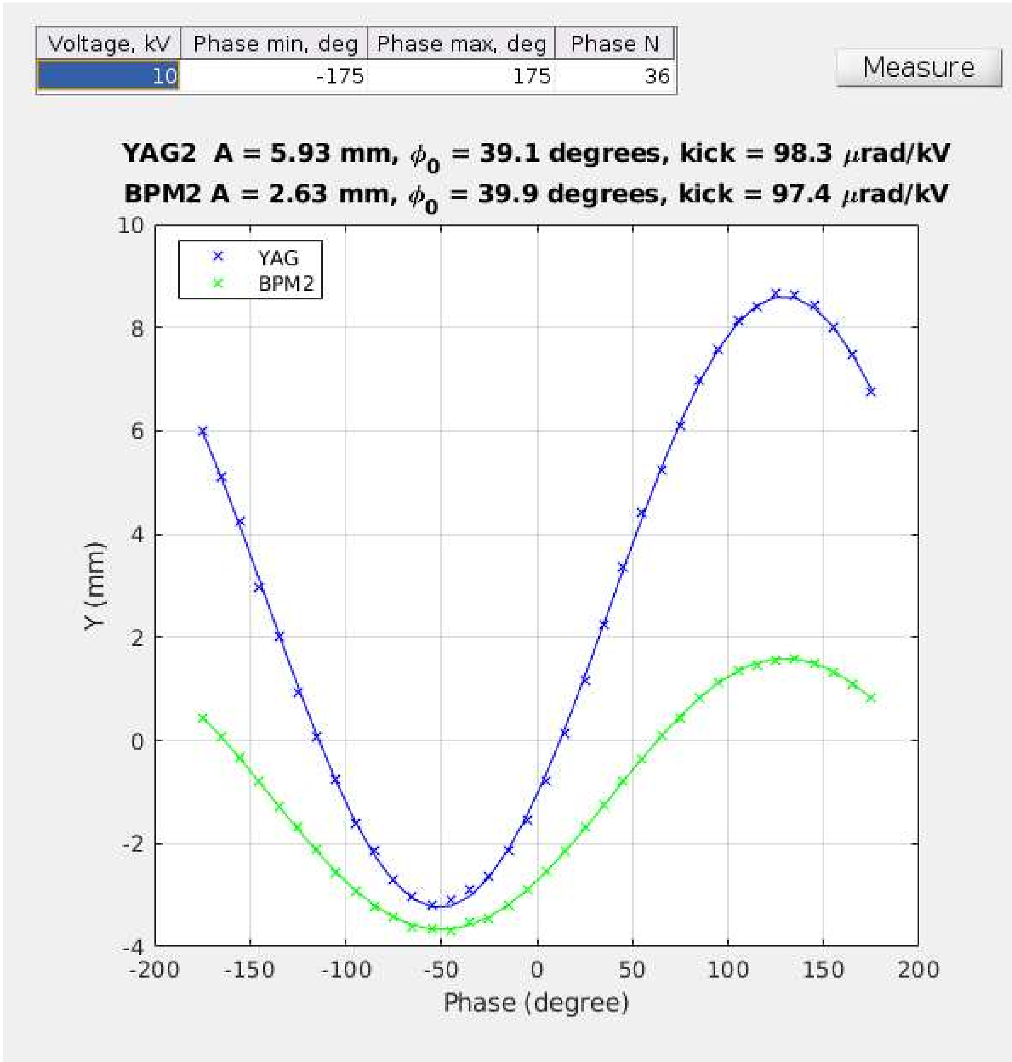

Figure 5: Phasing of the deflecting cavity.

The found from the scan transverse beam parameters can be used for the calculation of the beam functions at the YAG2 profile monitor. We are interested only in the beam size when beam is focused on the screen. It means that the α-function is zero at profile monitor. The β-function then can be found from the transport matrix using simplified formula

$$\beta_{YAG2} = \frac{2.33^2}{\beta_{Q4}}$$

Now we can withdraw the YAG3 profile monitor and propagate beam to the YAG2. The quadrupoles' strength is adjusted to focus the beam, and the deflecting cavity is turned on. The application the collect and process data. The application screenshot is shown in Fig. 7.

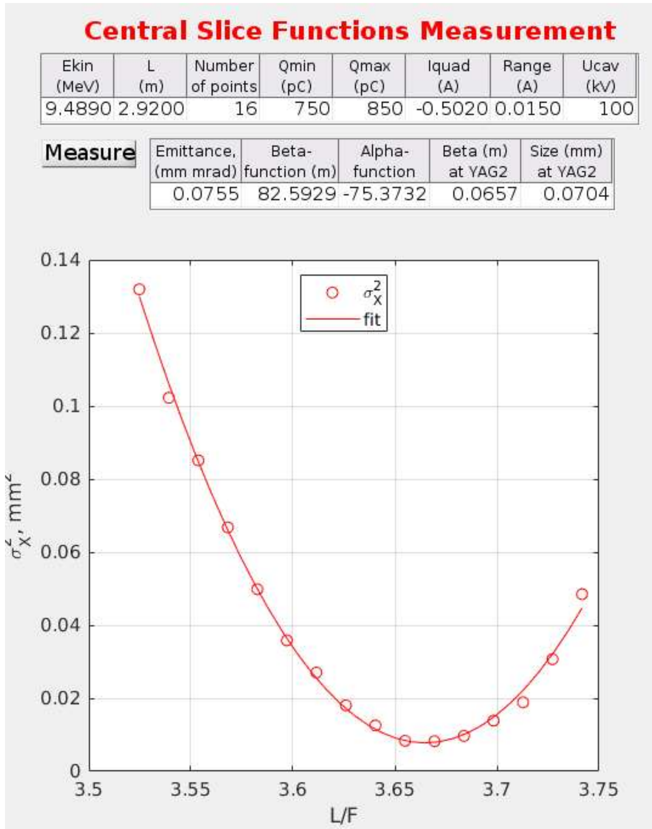

Figure 6: Measurement of the transverse beam parameters for the central slice in the horizontal plane.

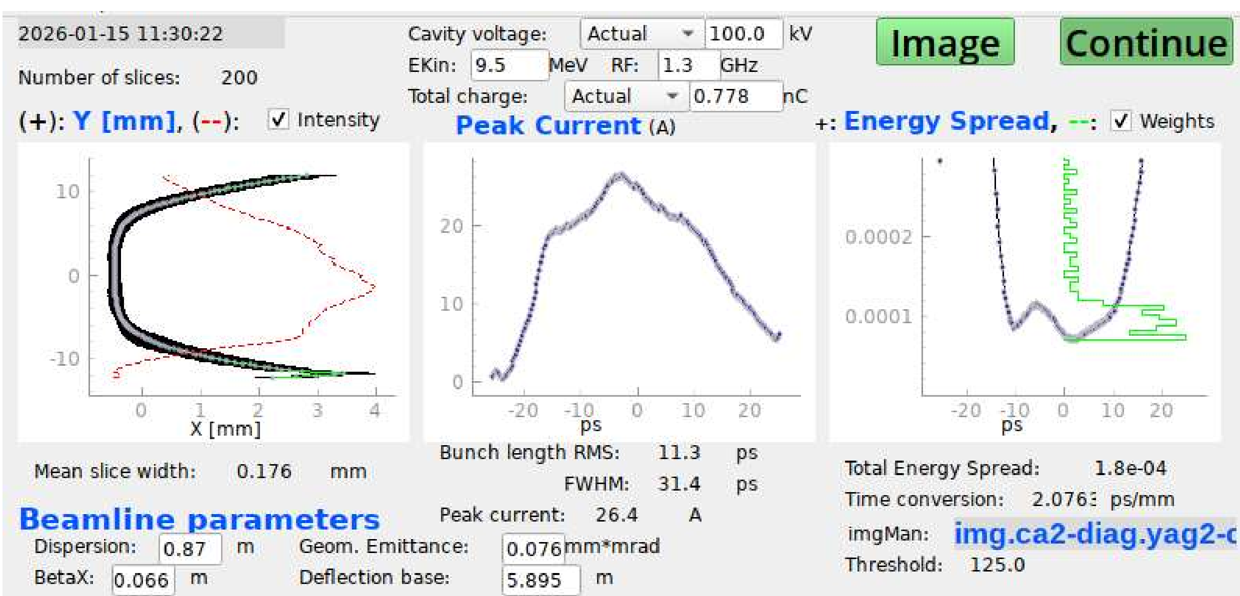

Figure 7: Screenshot of the application measurement of the energy spread.

The cavity voltage is received from the control system as well as beam charge. Dispersion value, beam energy, cavity frequency, deflection base used for the time calibration are programmed into application but can be changed. Beam functions are entered by operator. The application has three graphs. In the center the current profile is shown. On the left side the energy profile is shown: the black line shows average energy; the dotted red line juxtaposes the current profile. On the right graph the energy spread is shown.

Not only the energy spread matters but the change of the average energy with time. While it possible to see this dependence on the left side, it more convenient to observe the image directly on the beam image on the profile monitor as shown in Fig. 8. The beam image should be parallel to the displayed vertical line. The energy slew is eliminated by adjusting linac phase.

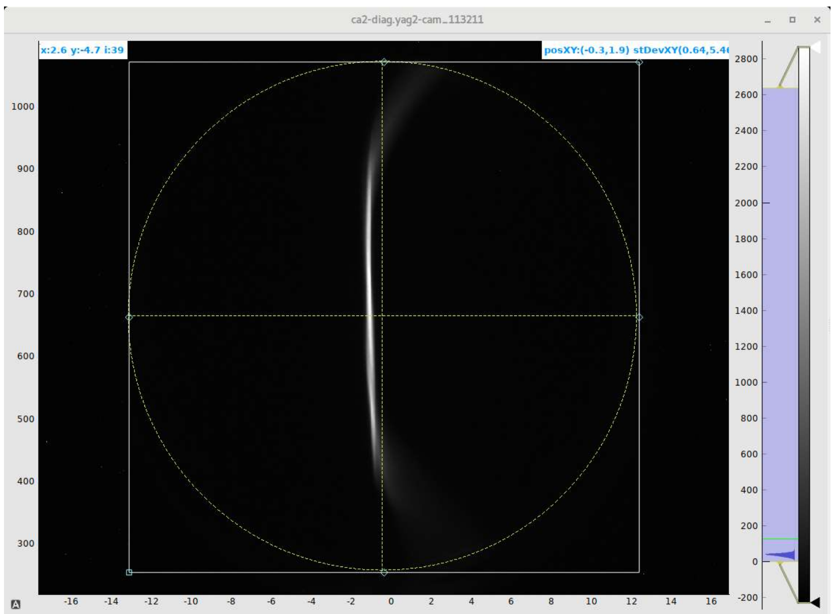

Figure 8: Image of the electron beam on the YAG2 profile monitor with deflecting cavity on.

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2. J. Ma, G. Wang, V. N. Litvinenko, “Simulation Studies of Plasma Cascade Amplifier”, in Proc. IPAC2021, doi:10.18429/JACoW-IPAC2021-WEPAB266

3. I. Pinayev, “Measurement of Slice Emittance with Deflecting cavity and Slit”, in Proc. IBIC2023, Saskatoon, Canada, doi:1 0.18429/JACoW-IBIC2023-MOP046