Ionization Profile Monitor design and experiments in HIRFL-CSR

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To meet the needs of real-time profile monitoring, injection match optimization, transverse cooling mechanism research in HIRFL-CSR, as well as the profile measurement of future intense facilities like HIAF and CiADS in Huizhou China, some IPM research and experiments has been done since 2013. In 2016, the first IPM was installed at HIRFL-CSRm with MCPs, phosphor screen and camera acquisition system. Then a new horizontal IPM with different framework was also deployed in CSRm at 2018 summer. Meanwhile the fast IPM with magnet and anode-electronics acquisition system, as well as the compact IPM of one inserted structure being able to detect horizontal and vertical profiles, are both now under design. This paper mainly presents the design and experiments of new horizontal IPM for transversal electron cooling and normal operation mode orbit study at HIRFL-CSRm in December 2018.

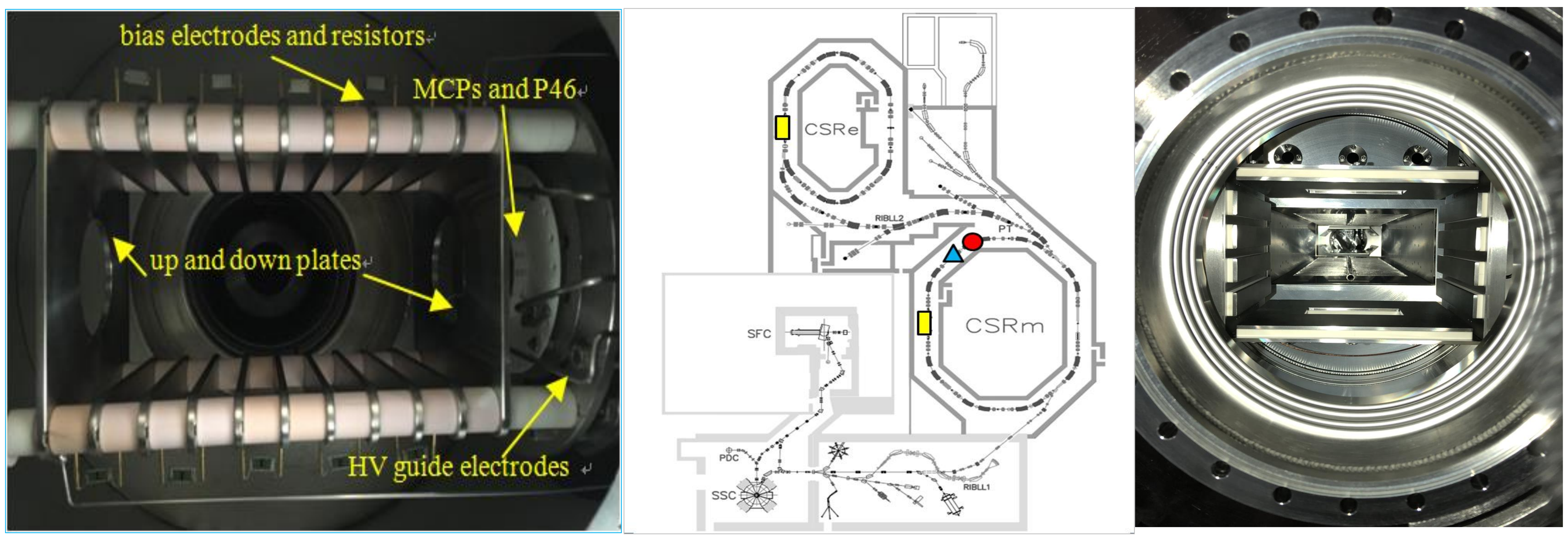


Fig 1. Left and right pictures are IPM-V and IPM-H, marked with red circle and blue triangle respectively in middle, where the yellow rectangles represent the two electron coolers in the CSRe and CSRm of HIRFL, Lanzhou, China.

IPM mainly collects ions or electrons originating from the residual gas ionization during the beam passage. Fig. 1 left is the vertical IPM tested in SSC Linac, which using tandem resistors for bias voltage like most IPMs in the world now. Right is the horizontal IPM with new framework design and less electrostatic field distortion. In case of the units degradation inside vacuum chamber undergoing harsh thermal baking and beam loss irradiation, new IPM utilizes separate electrodes for HV supply instead of tandem resistors. This causes HV expense, but allows some valuable experiments to validate the probe performance with variable HV settings, as well as to explain some experiment anomalies.

Design concerns and criterion:
Basically three factors affect the IPM property.

1. Initial velocity of signal particle. Usually ions has a negligible velocity than e^-, and ultra HV and magnet field can suppress its effect.
2. Space charge effect. It dominates the distortion in intense beam, while beam induced electromagnetic force is small in HIRFL-CSRm case with below mA current .

$$|F_{em}| = e(|\vec{E_r}| + |\vec{v} \times \vec{B}|) = \frac{I}{2\pi\varepsilon_0 \beta c \gamma^2} \cdot \frac{1}{r}\left(1 - e^{-r^2/2\sigma^2}\right), \quad (1)$$

3. E-field nonuniformity. It can be optimized by mechanism design and even HV settings, which is -7.5% with 0-6 kV at this case.

Generally total 10% error is acceptable!

Due to small transverse emittance, new IPM is developed as ion collection mode with dual MCPs, P46 and optics acquisition. The space uncertainty of MCP is generally 2.5 times the core diameter of 20 um, thus the optics system spatial resolution calibrated about 63 um seems convincing.
The 4.2 Megapixels SCMOS chip using double Camera Link for data transmission can reach 100 fps. Data processing was built on EPICS ioc to realize multiple functions such as ROI, fitting, trigger, historical profile display et al. The whole system achieves about 300 ms with full resolution, which is much less than the camera response of 10 ms and mainly results from massive data processing via upper PVs rather than in FPGA.

CSRm IPM Control Plane

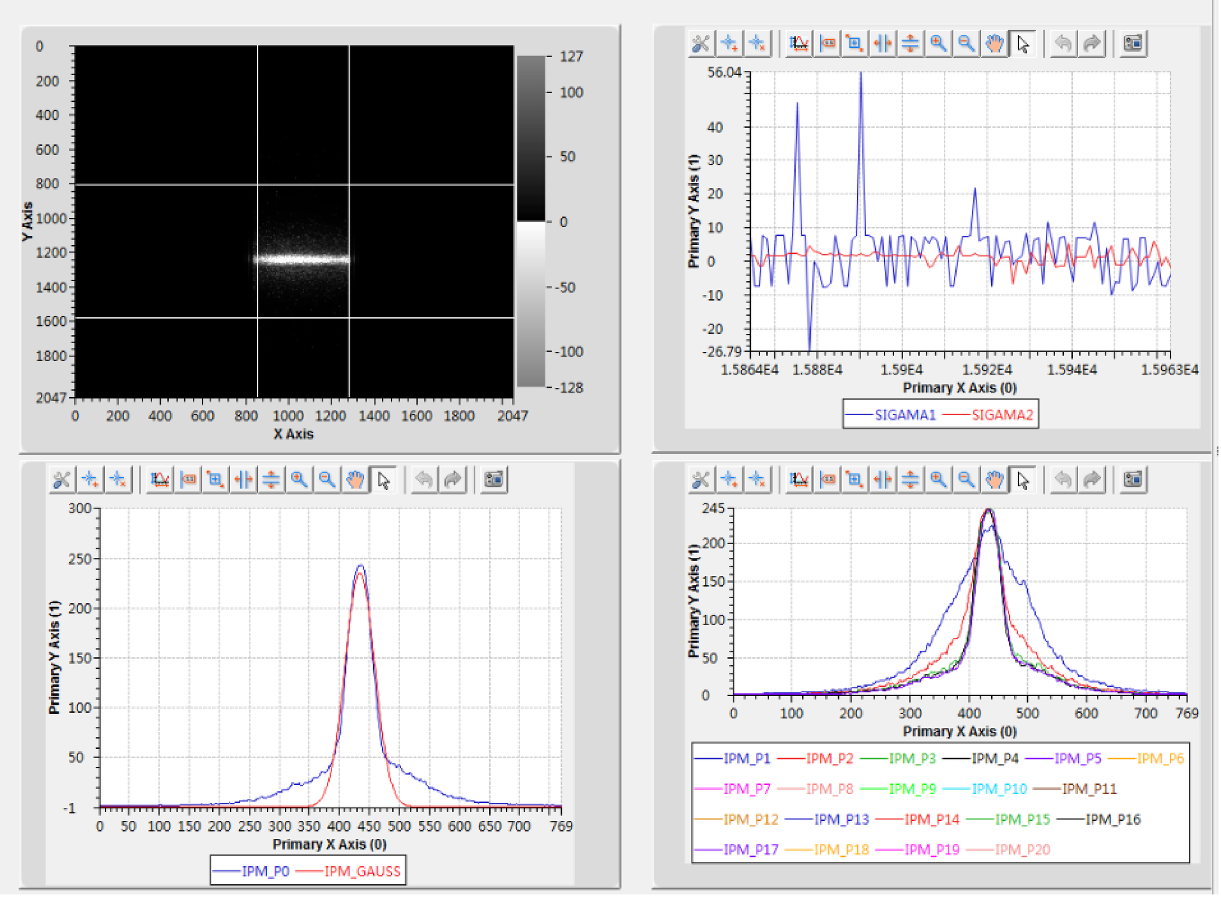
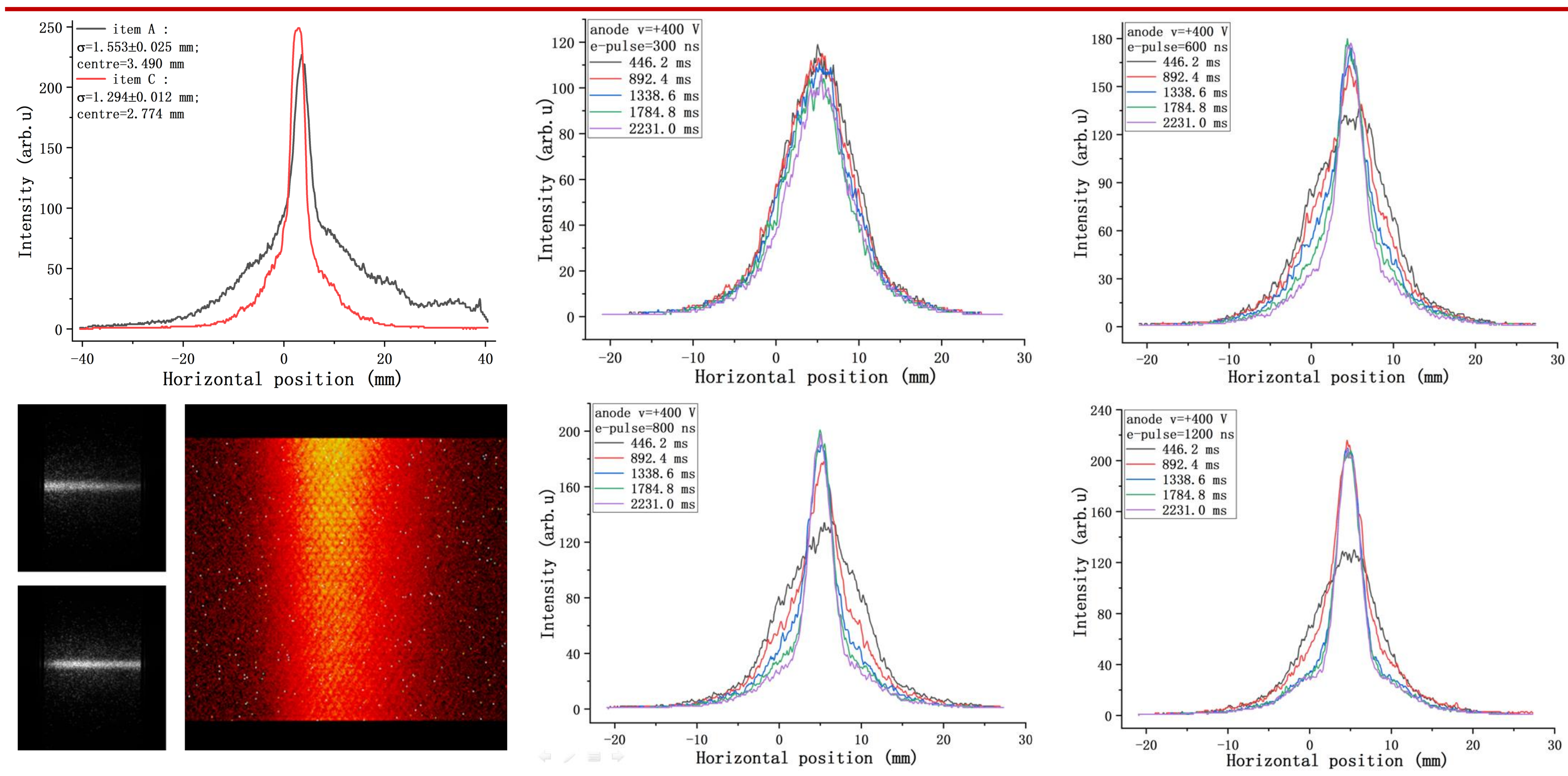


Fig 2. The IPM control system is upgraded with EPICS ioc to achieve multiple functions like ROI, trigger and fitting et al.



Left upper indicates different field distortion with 0-6 kV (item A) and ±2 kV (item C) HV settings, under beam of Kr^{28+}, 4.9 MeV/u, 400 uA.

Left down (2 white lights) shows longitudinal asymmetry, which even disappear and repeated among different HV settings. This phenomenon probably results from Zero potential on the upper MCP, rather than transverse emittance or longitudinal variation influence in such a short Z distance and multiturn average measurement .
Left down (red light) recited from Jülich IPM discovered the same longitudinal anomaly.

Right 4 figures reveal the electron cooling strength varies with different e-pulse length from the electron gun, which apparently show a positive correlation. Other e-cooling parameters like frequency and anode voltage also have been tested with IPM, not posted here.

Fig 3. Left upper and down: profile VS variable HV. Right 4 pic is transverse cooling effect VS variable e-pulse length.

IPM measures the normal operation cycle of HIRFL-CSRm to be 16.45 s, which consists of 0-10 s accumulation, 10-14.6 s of acceleration, following with about 2 s for magnet hold, then fast extraction into HIRFL-CSRe. The obtained 16.45 s cycle agrees well with the official design of 17 s. Moreover, the IPM measurements reveal both beam size and center position went through a large vibration during the 10-14.6 s acceleration time.

With the IPM composed of electron collection, multiple anode and electronics acquisition fast up to few tens MHz, further experiments like turn by turn profile resolution can be realized.

In ref: J.W. Xia et al, NIMA 488 (2002) 11–25, the HIRFL –CSRm normal operation mode was designed with a dipole ramping rate of 0.1-0.4 T/s, resulting in 10 s time of accumulation, 3 s acceleration time and a total cycle period of 17 s.

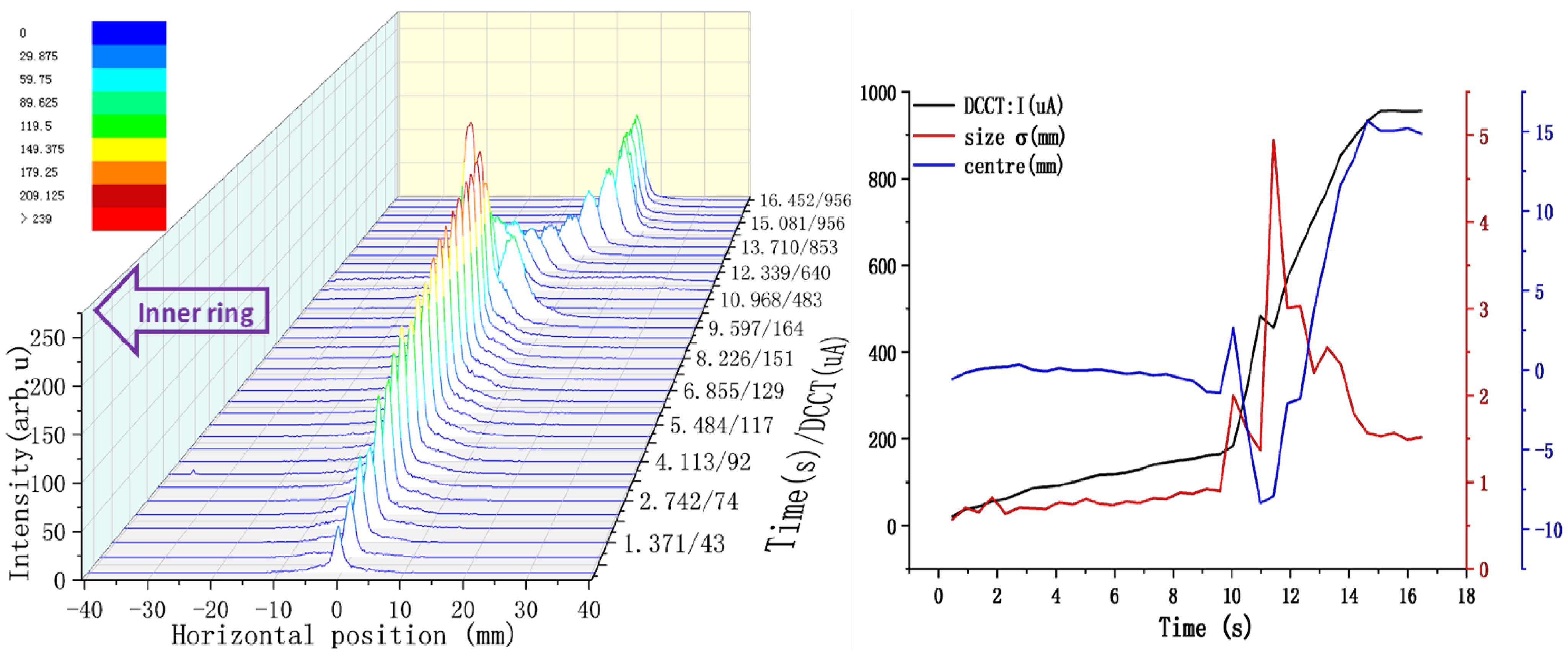


Fig 4. Transverse orbit variation within a 17 s cycle of normal injection, accumulation, acceleration in CSRm, then extraction to CSRe, with the electron cooling working on beams of Kr^{30+}, 4.9-422 MeV/u.