Simulation of bunched Schottky spectrum for laser-cooled O^{5+} ions at CSRe

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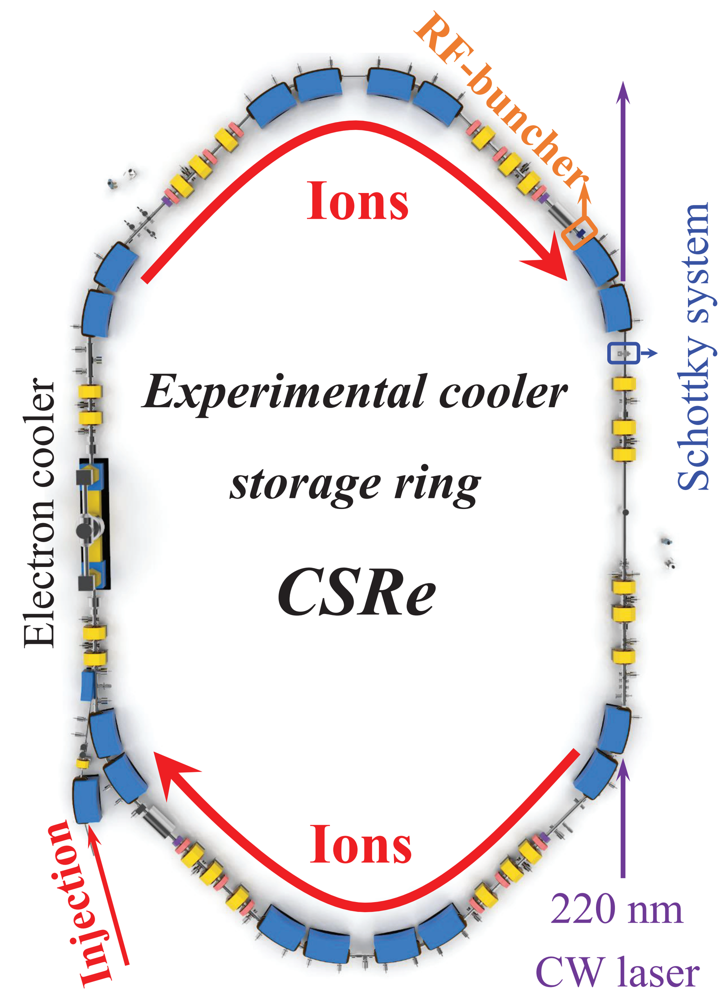
Abstract: Laser cooling of lithium-like O^{5+} ion beams with an energy of 275.7 MeV/u was firstly achieved at the storage ring CSRe in Lanzhou, China [1]. However, the experimental Schottky spectrum of bunched ion beams has not yet been fully understood. For example, how to understand the 'coherent effect' for the powerful central peak as shown in Fig. 3, how to extract the momentum spread of the laser-cooled bunched ion beams, etc. In order to solve these problems, we simulate the Schottky spectrum of bunched O^{5+} ion beams by employing the multi-particle tracking method. By tracking the trajectory of synchrotron oscillation for bunched ions in phase space and using the Fast Fourier Transform (FFT), we simulate the Schottky spectrum of both uncooled and laser-cooled bunched ion beams and the results are shown in Fig. 5.

Laser cooling of O^{5+} ion beams at the CSRe



Beam parameters	
Circumference	128.80 m
Ion species	$^{16}O^{5+}$
Beam energy	275.7 MeV/u
Relativistic β, γ	0.64, 1.30
Revolution frequency	1.48 MHz
Slip factor η	0.45
Harmonic number h	33
Cooling transition	$2s_{1/2} \leftrightarrow 2p_{1/2}, 2p_{3/2}$
Transition wavelength	103.76 nm, 103.19 nm
Transition lifetime	2.44 ns, 2.40 ns
Laser system	
Laser wavelength	220 nm
Laser power	> 40 mW
Scan range	20 GHz

Fig. 1. (left) Schematic view of the experimental setup for laser cooling of $^{16}O^{5+}$ ion beams at the CSRe, and (right) the parameters for the experiment.

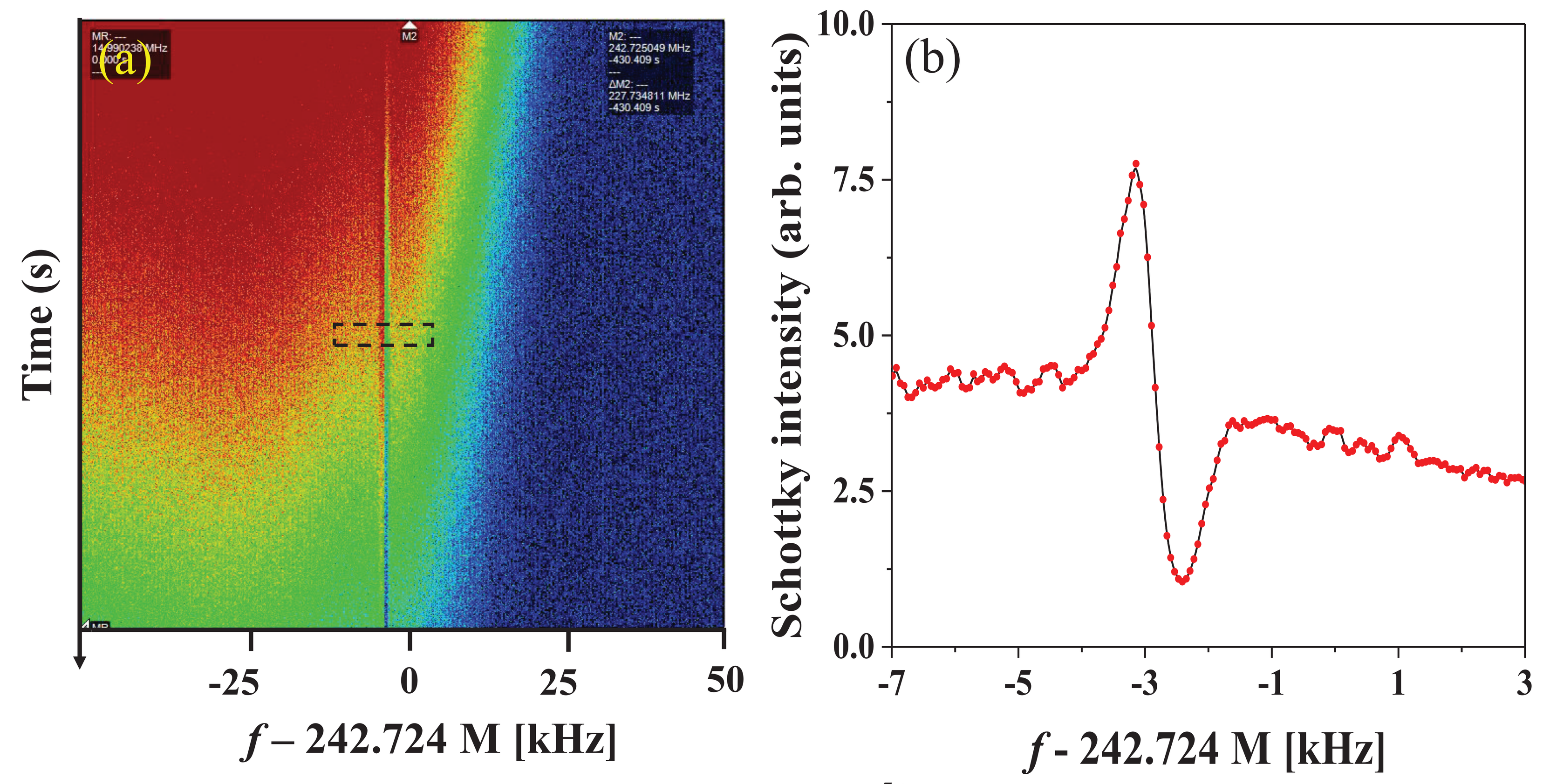


Fig. 2. (a) Schottky spectrum of coasting O^{5+} ion beams interact with a fixed laser. (b) The Schottky intensity signals extracted from figure 2(a).

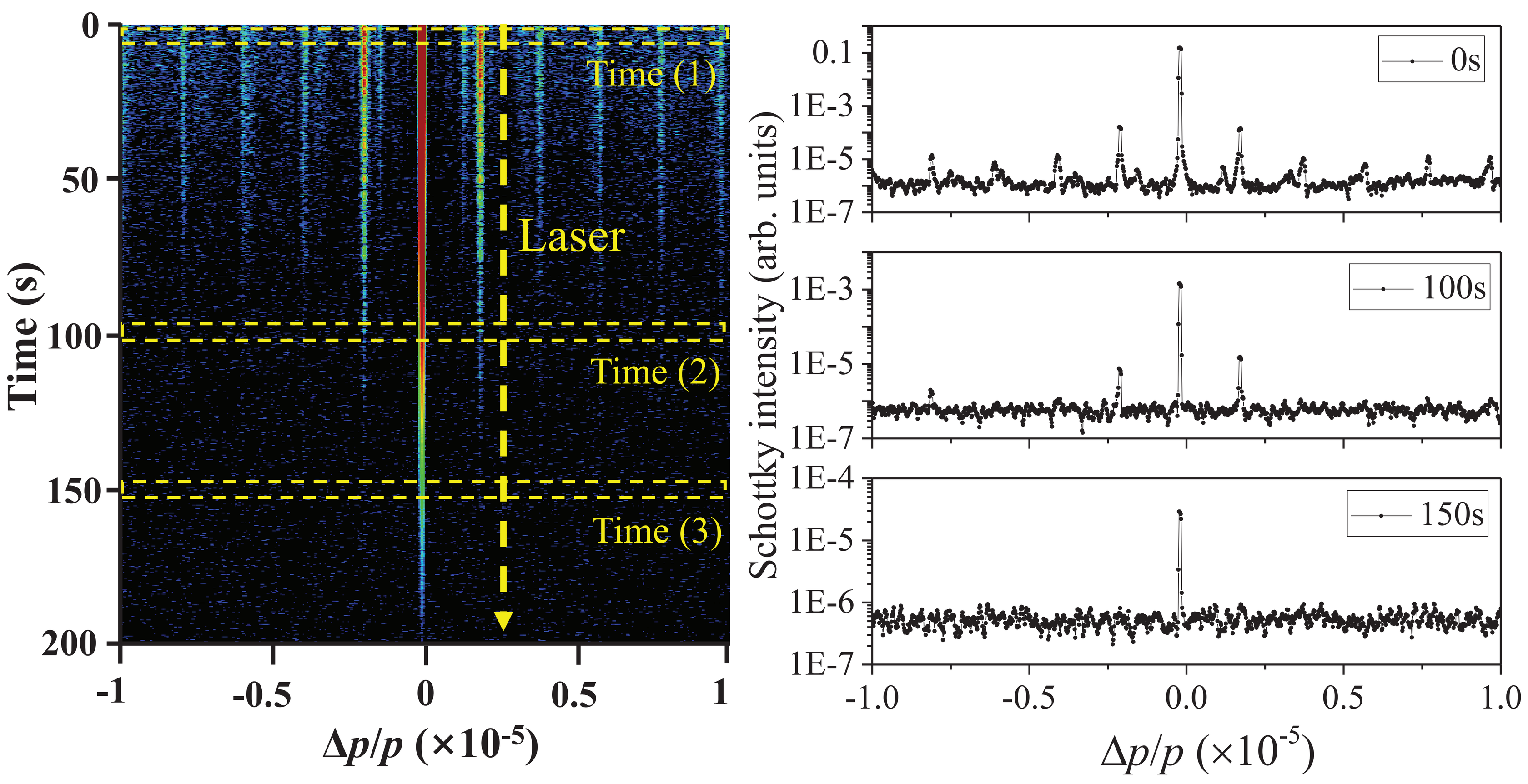


Fig. 3. Schottky of laser-cooled O^{5+} ion beams by a CW laser and an RF-buncher. The Schottky intensity in different time was extracted and shown in figure 3(b).

Simulated Schottky spectra of bunched ion beams

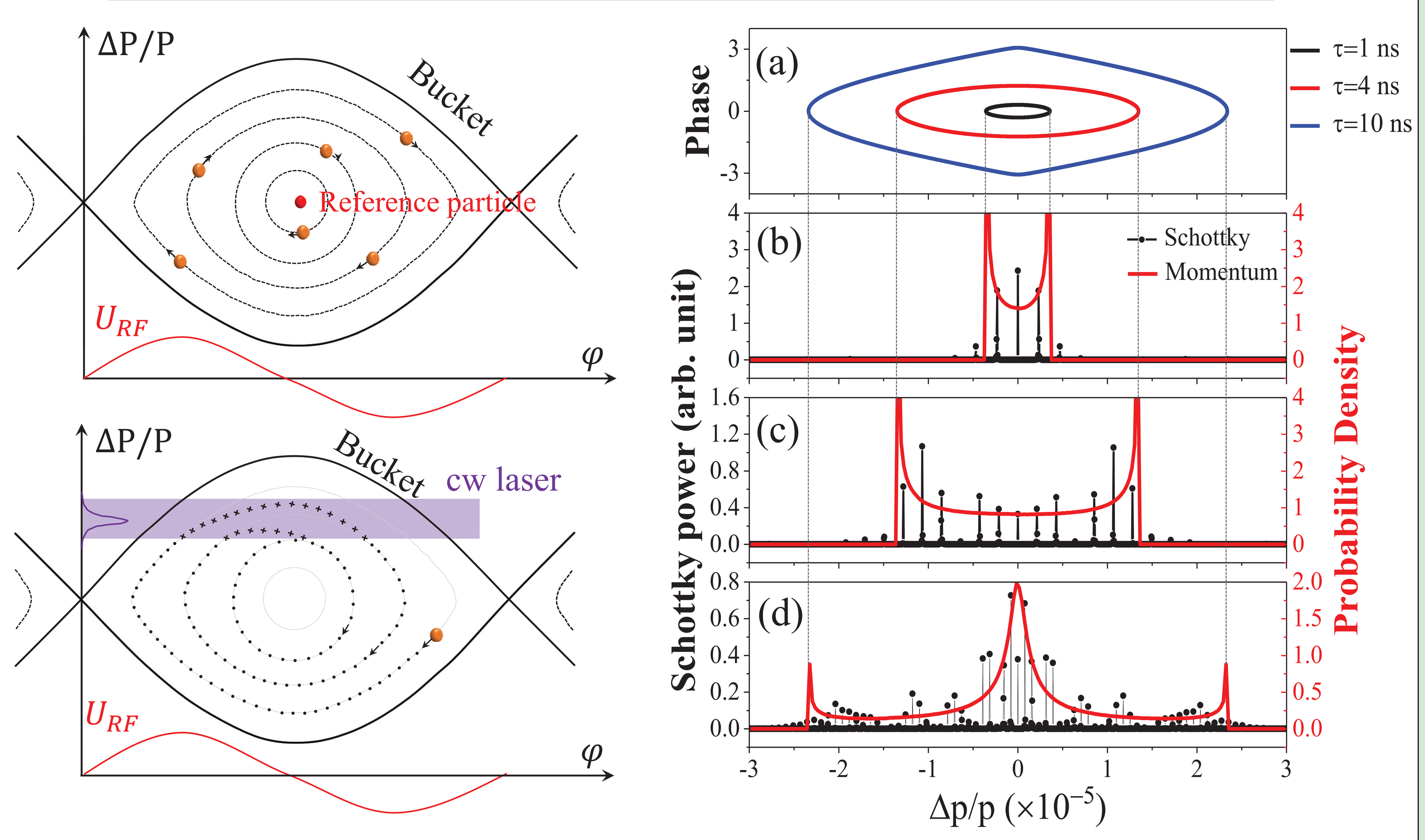


Fig. 4. (left) Sketch of the trajectory of synchrotron oscillation of uncooled and laser-cooled bunched ions in phase space. (right) The momentum probability density of the ions with different oscillation amplitudes and the corresponding Schottky spectra.

Simulated of laser-cooled bunched O^{5+} ion beams

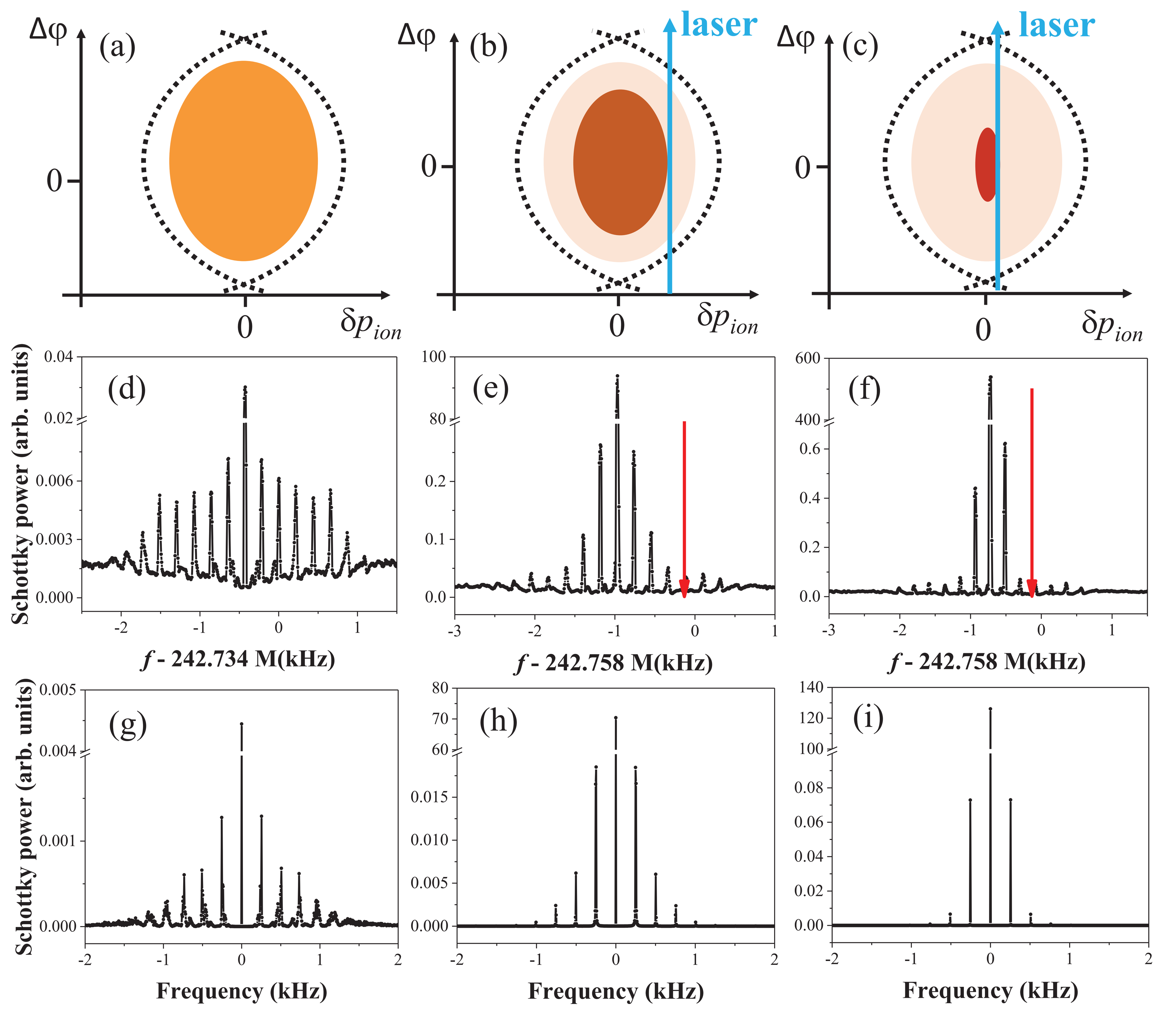


Fig. 5. Experimental and simulated longitudinal bunched Schottky spectra of uncooled and laser-cooled O^{5+} ions at the CSRe. Figure (a)-(c) are the phase space distribution of the ions inside of the bucket, figure (d)-(f) and (g)-(i) are the corresponding experimental and simulated Schottky spectra.

Conclusion & Outlook

We successfully achieved laser cooling of relativistic O^{5+} ion beams at the storage ring CSRe and also developed a simulation code for Schottky spectrum of bunched ion beams. The main achievements are shown below:

- Firstly achieved laser cooling of O^{5+} ion beams at the storage rings. It is the highest charge state, highest beam energy and shortest transition wavelength for laser cooling experiments up to now.
- Developed a simulation code for Schottky spectrum of laser-cooled bunched ion beams at the storage rings.
- Simulated the Schottky spectra of laser-cooled bunched ion beams and confirmed the 'coherent effect' for bunched ion beam at the storage rings.

Based on the laser cooling experiment and simulation work, we will further study the dynamics of laser-cooled ion beams. Besides, we will also investigate the Schottky spectrum of the ions outside the bucket.

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Reference:

[1] W. Q. Wen, et al., *Hyperfine Interact.* **240** (2019) 45

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