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Nonlinear-Energy-Spread Compensation and Time-resolved Measurement of Wake fields in Corrugated Structures

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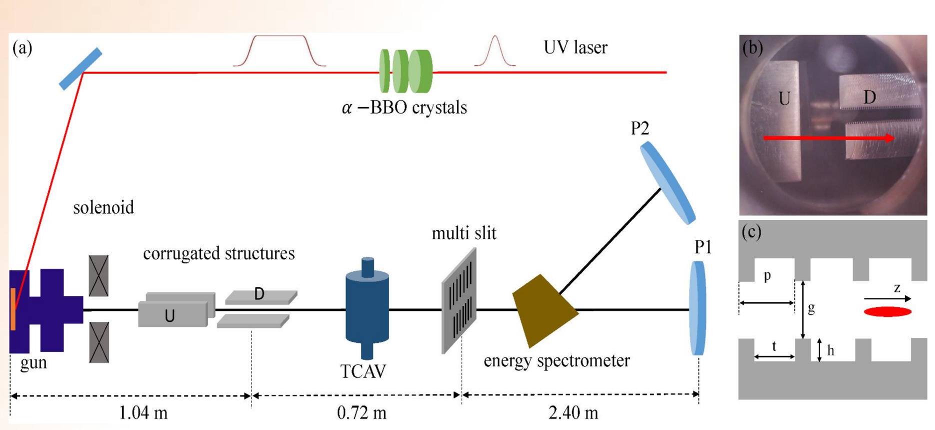
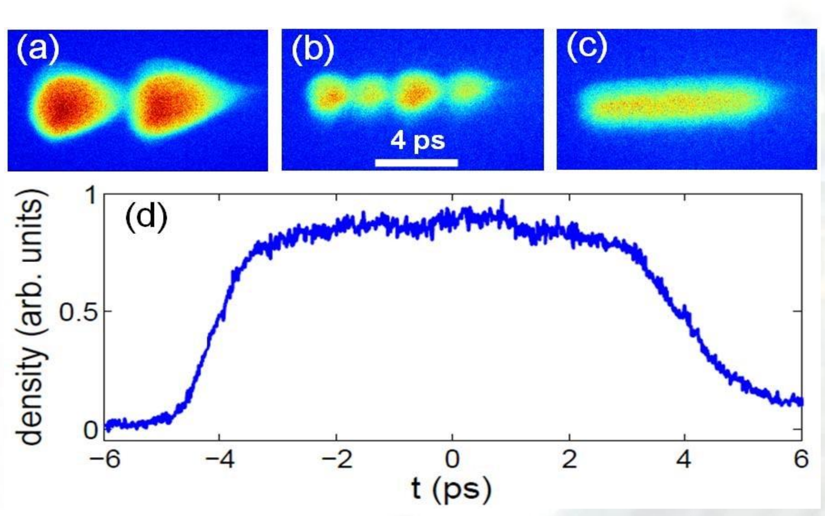
Abstract

High quality electron beams with flat distribution in both energy and current are critical for many accelerator-based scientific facilities such as free-electron lasers and MeV ultrafast electron diffraction and microscopes. We report on using planar corrugated structures to compensate for the beam nonlinear energy chirp imprinted by the curvature of the radio-frequency field, leading to a significant reduction in beam energy spread. It is shown that while the time dependent quadrupole wake field produced by a planar corrugated structure causes significant growth in beam transverse emittance, it can be effectively canceled with a second corrugated structure with orthogonal orientation. The strengths of the time-dependent longitudinal and quadrupole wake fields are also measured and found to be in good agreement with theories. This work also extends the applications of corrugated structures to the low beam charge (a few pC) and low beam energy (a few MeV) regime and may have a strong impact in many accelerator-based facilities.

I. Experiment layout



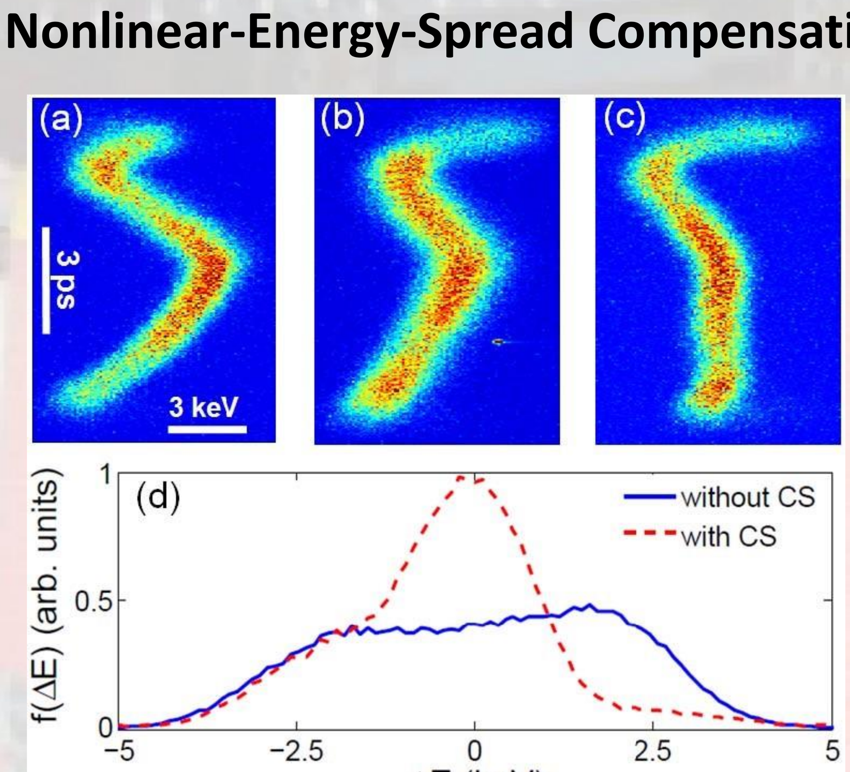
II. UV Gaussian pulses stacker



Time-resolved measurements of beam distribution at screen P1 with (a) 1 crystal, (b) 2 crystals, and (c) 3 crystals; the corresponding beam current distribution with 3 crystals inserted is shown in (d).

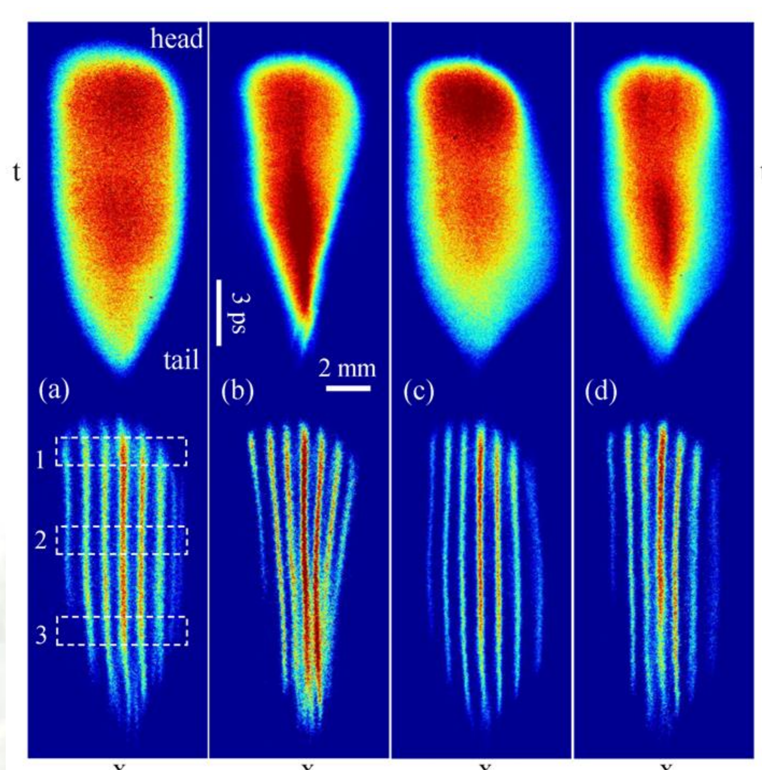
III. Experimental Result

A. Nonlinear-Energy-Spread Compensation

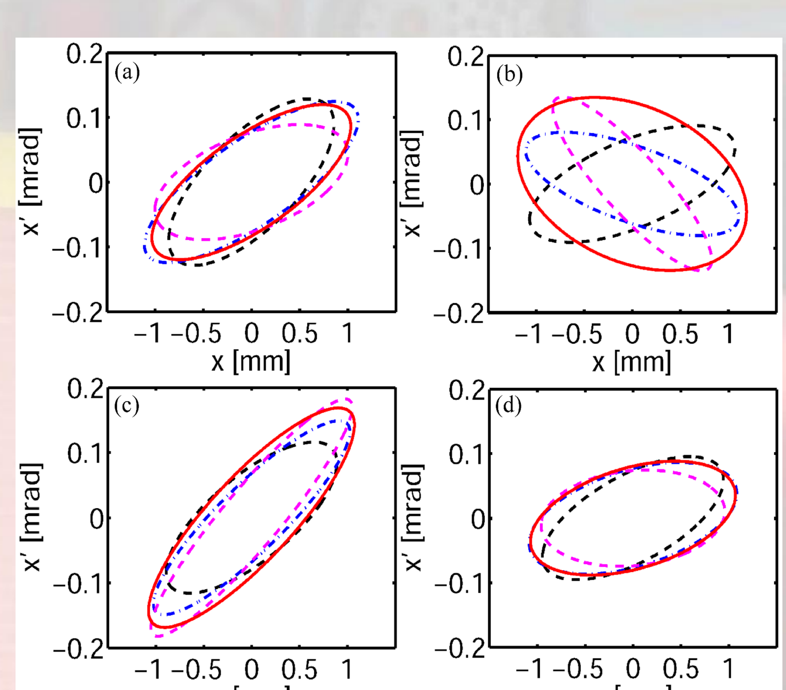


Time-resolved measurements of beam longitudinal phase space distributions (bunch head to the up) at screen P2 (a) with the two structures open, (b) with one of the CS gap reduced to 3 mm, and (c) with the gaps of the two CS both set at 3 mm; (d) the corresponding projected beam energy distribution.

B. Cancellation of time-dependent quadrupole wake

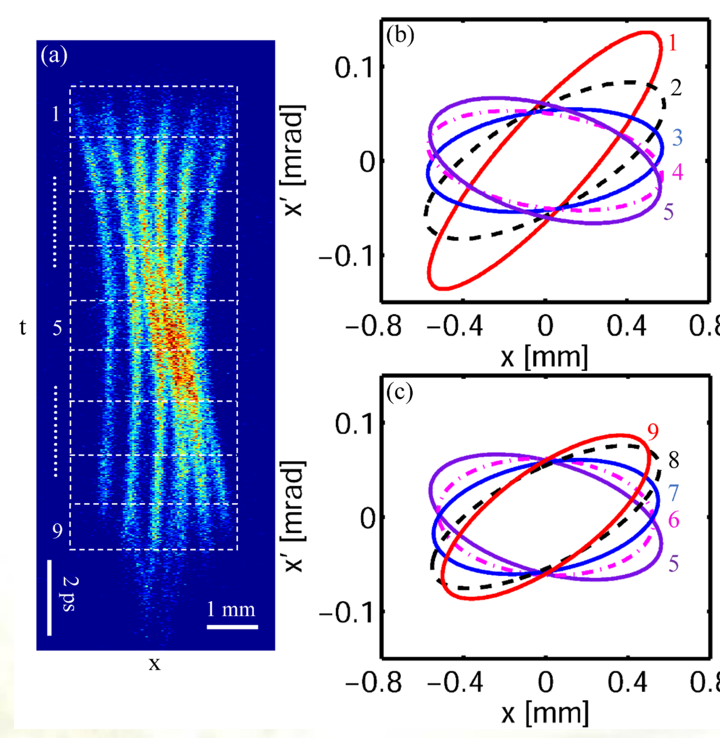


Time-resolved measurements of beam (top) and beamlets (bottom) distribution on screen P1. Four situations are shown: (a) with two CS widely open; (b) with downstream CS gap set at 3 mm; (c) with upstream CS gap set at 3 mm; (d) with both CS both gaps set at 3 mm. The dashed squares in (a) indicates the three representative slices used for analysis of emittance and phase space



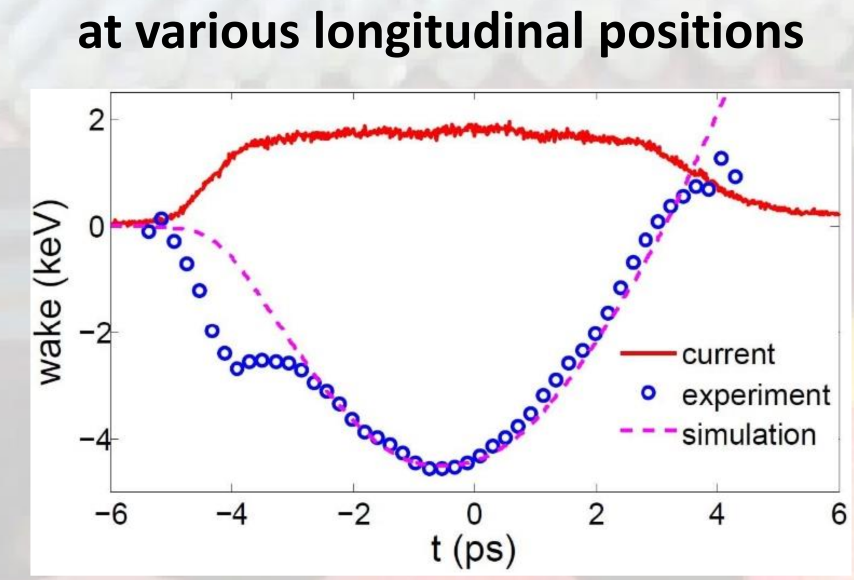
Slice and projected phase space ellipses in four situations : (a) with two CS widely open; (b) with D CS gap set at 3 mm; (c) with U CS gap set at 3 mm; (d) with both CS gaps set at 3 mm. The phase spaces for the head slice, central slice and tail slice are shown with dashed black line, dotted dashed blue line and dashed magenta line, respectively. The projected phase space is shown with solid red line.

C. Orientation of slice phase space ellipses

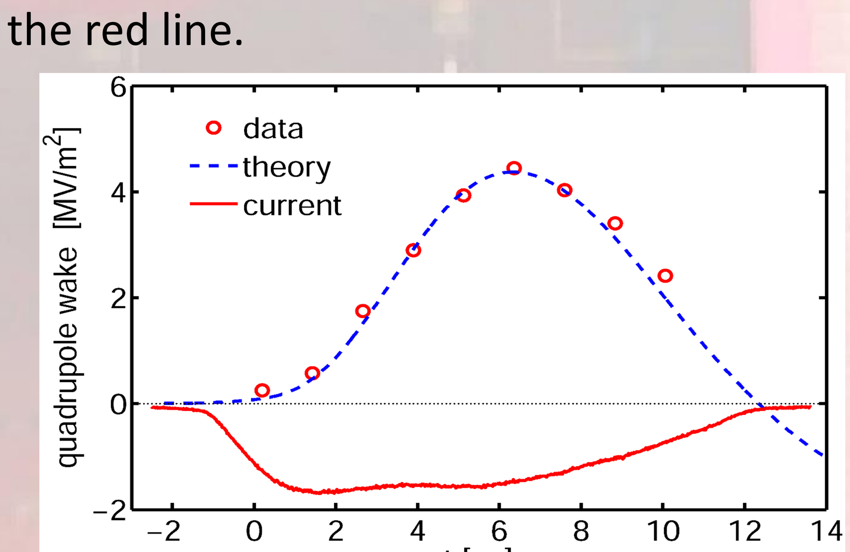


(a) Streaked beam distribution with the gap of the downstream CS reduced to 1.4 mm; (b) Phase space ellipses for the front five slices (from bunch head to bunch center); (c) Phase space ellipses for the latter five slices (from bunch center to bunch tail).

D. Time-dependent wake fields at various longitudinal positions

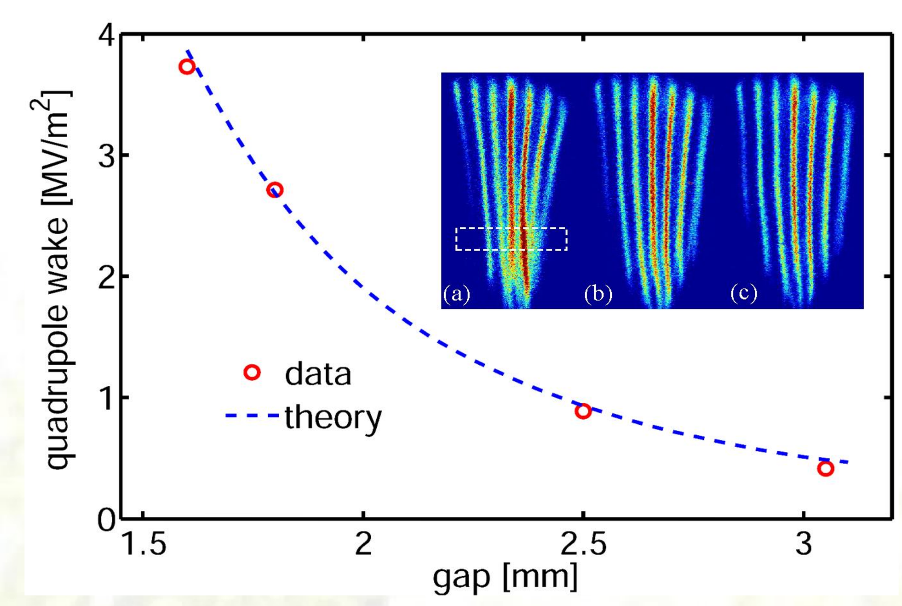


Measured and simulated longitudinal wake potential of the CS. The bunch distribution, with the head to the left, is also shown with the red line.



Measured (red circles) and simulated (blue dashed line) time-dependent quadrupole wake fields with the gap of downstream CS set at 3 mm. The beam longitudinal distribution is also shown in red solid line.

E. Time-dependent quadrupole wake fields at various gaps



Measured (red circles) and simulated (blue dashed line) quadrupole wake fields of the central slice at various gaps. The streaked beamlets at various CS gaps are shown in the insets [(a) for g = 3:6 mm, (b) for g = 5:0 mm and (c) for g = 6:1 mm].The dashed square indicates the region of the central slice used for analysis.

IV. Conclusion

We have presented the measurement of beam phase space manipulation with CS in the low beam energy (a few MeV) and low beam charge regime (a few pC), providing important complementary information to previous worldwide efforts that focus on beams with high energy (~100 MeV and above) and high charge (~100 pC and above). In addition to directly showing the compensation of the beam nonlinear energy chirp with CS through measurements of the beam longitudinal phase space, we also provided a complete characterization of the quadrupole wake field in planar CS. It is demonstrated that while the time-dependent quadrupole wake field produced by a planar CS causes significant growth in beam transverse emittance, it can be effectively canceled with a second CS with orthogonal orientation. The results are in good agreement with simulations and should forward the applications of this technique in simplifying the design and enhancing the performance of many accelerator-based scientific facilities.

V. Acknowledgments

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