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Phase and Amplitude Calibration of the Sub-harmonic Buncher for the High Energy Photon Source Linac

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Abstract

The High Energy Photon Source (HEPS) Linac is a normal conducting electron linear accelerator capable of producing high bunch charge beam. Two Sub-harmonic bunchers (SHB) are included in its bunching system for longitudinal bunching to increase the bunch charge. The phase and amplitude of the SHB is crucial for achieving high-quality electron beam in Linac. This paper presents a method for calibrating the phase and amplitude of the SHB using the time-of-flight technique, and experiments were conducted based in the HEPS Linac and employing two Beam Position Monitors (BPMs). This paper presents detailed insights into both the simulation and experimental procedures

Calibration Theory

A. Single-particle Model

$$E_2 - E_1 = eV_{eff}cos(\phi + \phi_0)$$

$$t_{ToF} = \frac{L_1}{v_1} + \frac{L_2}{v_2} + \Delta t$$

B. Particle-bunch Model

$$\langle E_{2i} - E_{1i} \rangle = e\kappa V_{eff}cos(\phi + \phi_0 + \Delta\phi)$$

$$\kappa = \sqrt{\left(\frac{1}{N}\sum_{i=1}^{N} sin\Delta\phi_i\right)^2 + \left(\frac{1}{N}\sum_{i=1}^{N} cos\Delta\phi_i\right)^2}$$

$$\Delta\phi = arctan\left(\frac{\sum_{i=1}^{N} sin\Delta\phi_i}{\sum_{i=1}^{N} cos\Delta\phi_i}\right)$$

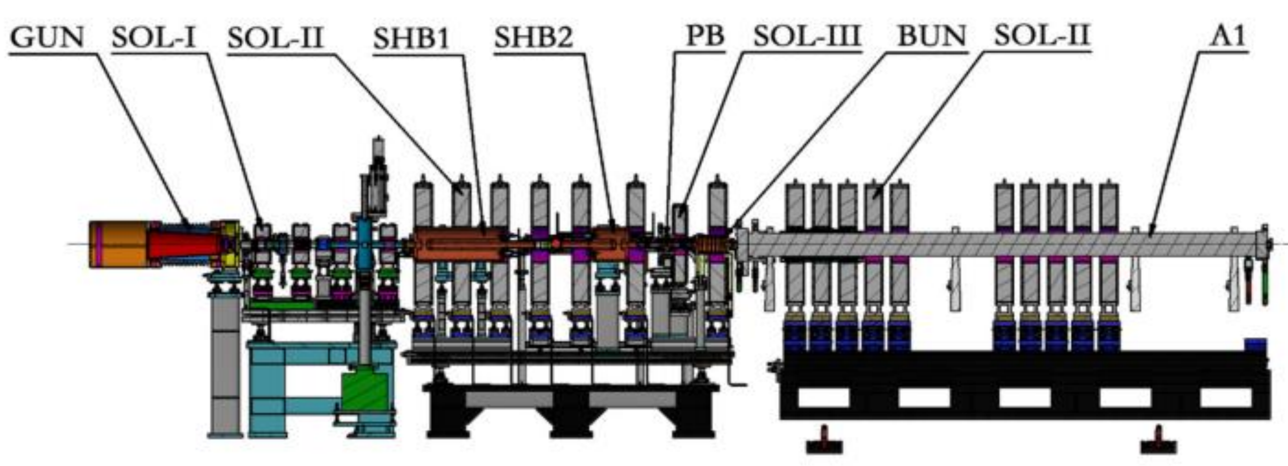

Fig. 1 Layout of the HEPS bunching system

Simulation Results

Beam dynamics simulations using ASTRA were conducted at bunch charges of 1.0 nC, 5.0 nC, and 9.0 nC with FWHM bunch lengths of 500 ps, 1000 ps, and 1500 ps. ToF was extracted using two methods—global averaging and truncated averaging—and their results are presented.

- **Global Averaging Method:**

  All particles are included in the calculation of the average Time of Flight.

Truncated Averaging Method:

- Only particles with densities above a specified threshold on the particle distribution are included in the average ToF calculation.

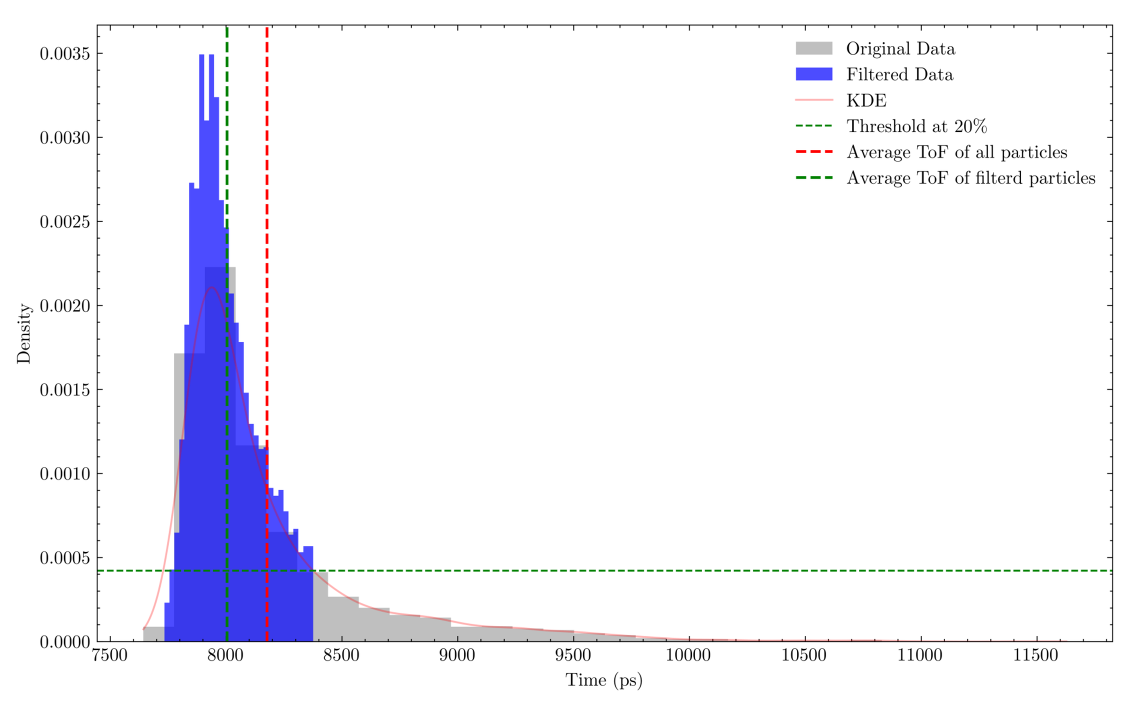

Fig.4 Difference between global averaging method and truncated averaging method

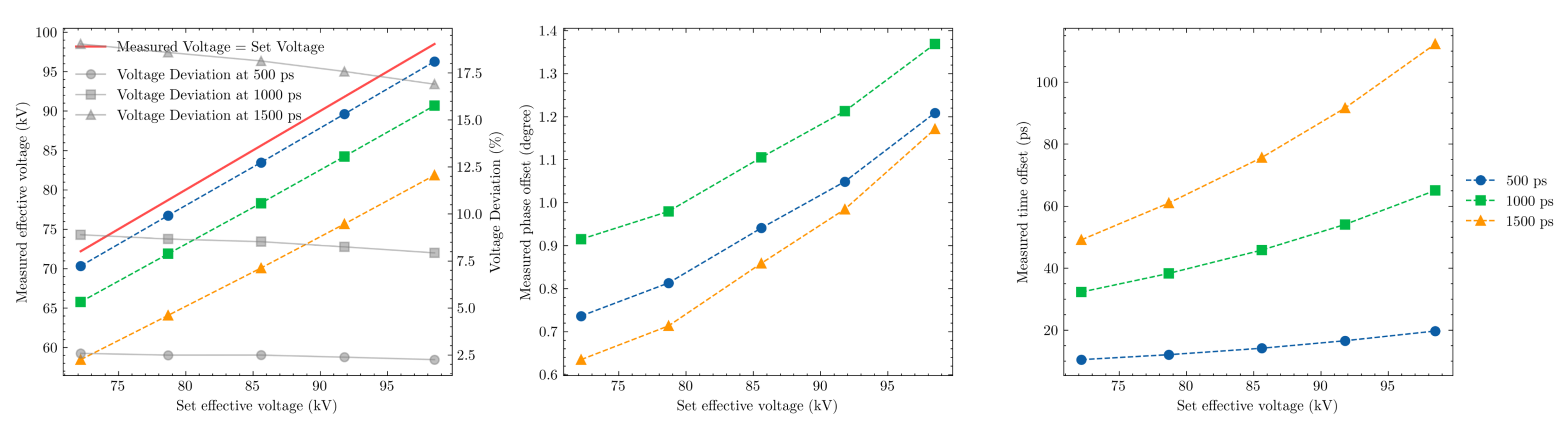

Fig.2 Simulation results. Single-particle model with global averaging method

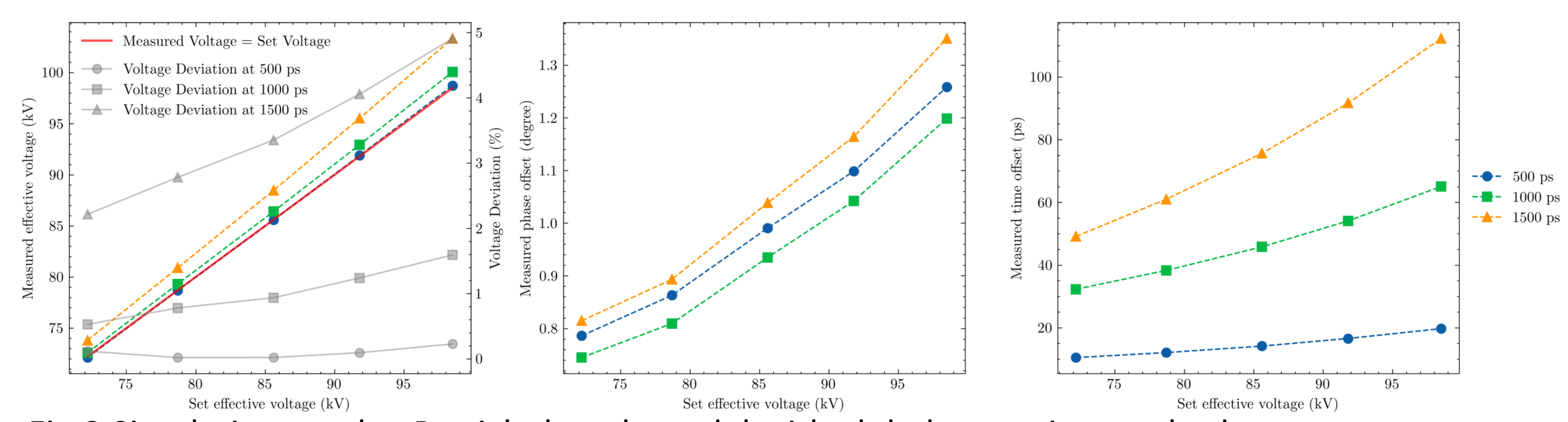

Fig.3 Simulation results. Particle-bunch model with global averaging method

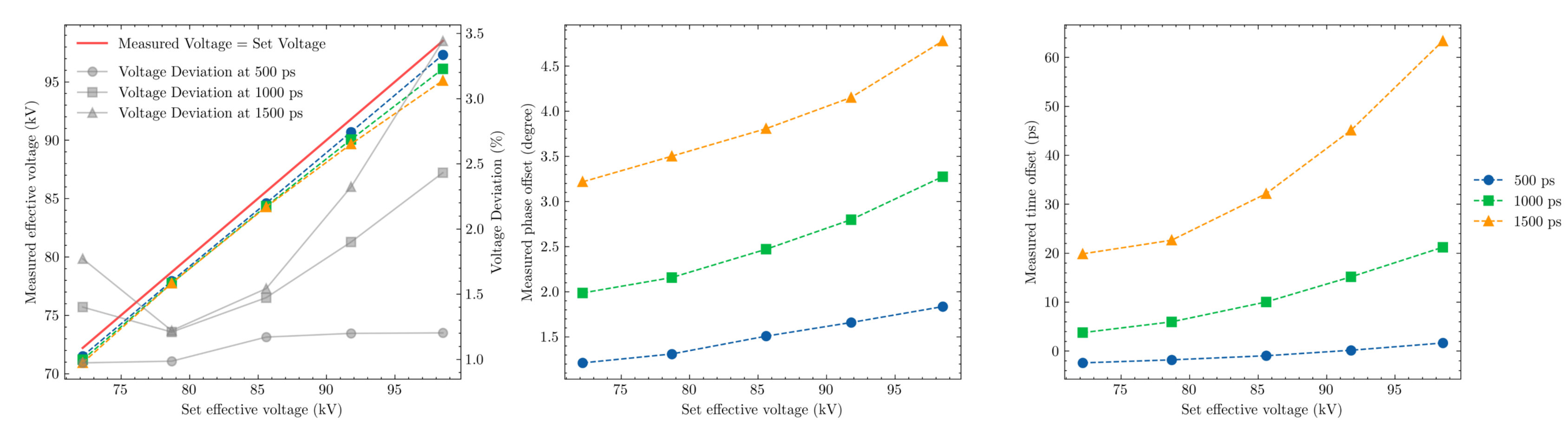

Fig.5 Simulation results. Single-particle model with truncated averaging method

Experimental Results

Multiple approaches were employed to extract the ToF data and derive the phase scan curve, including the use of peak, valley, and zero-crossing points to determine the time of flight.

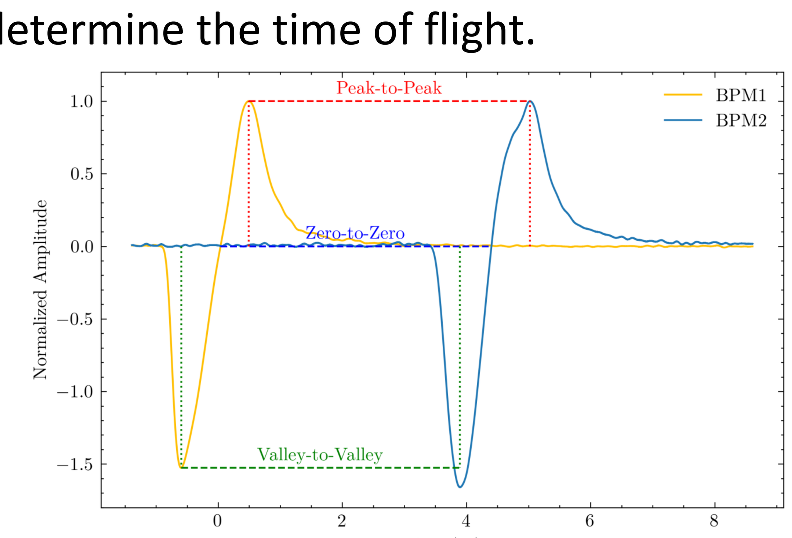

Fig.6 Signals from BPM1 and BPM2

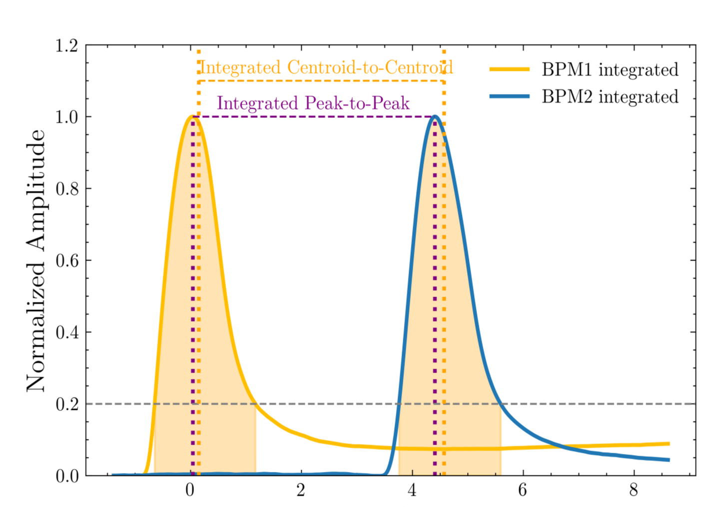

Fig.7 Integrated signals from BPM1 and BPM2

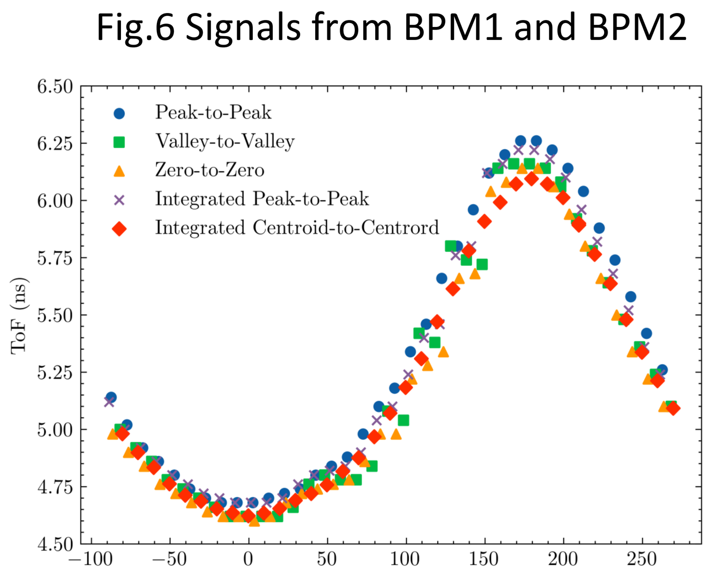

Fig.8 Comparison of phase scan curves obtained using different methods with 0.6nC bunch charge

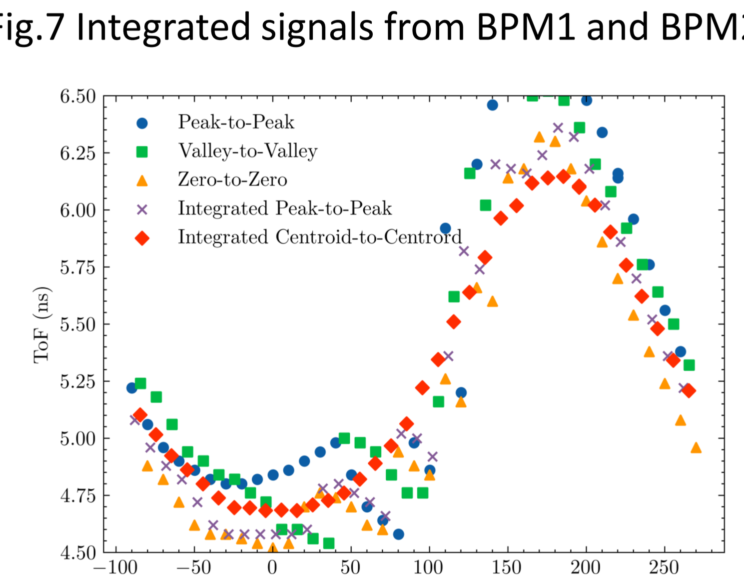

Fig.9 Comparison of phase scan curves obtained using different methods with 9.0nC bunch charge

As seen in Fig. 10, the time offset and its error bars show significant variation when the truncation percentage is below 20%. However, beyond 20%, these fluctuations become minimal. Thus, the truncation percentage was set to 20%.

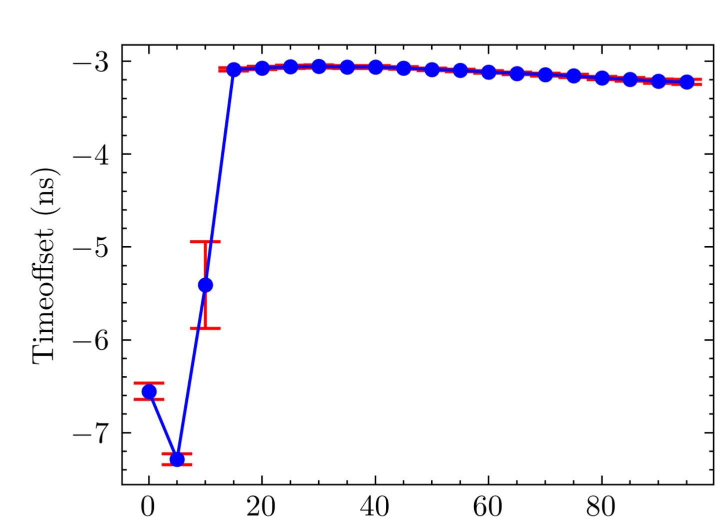

Fig.10 Timeoffset as a function of truncation percentage

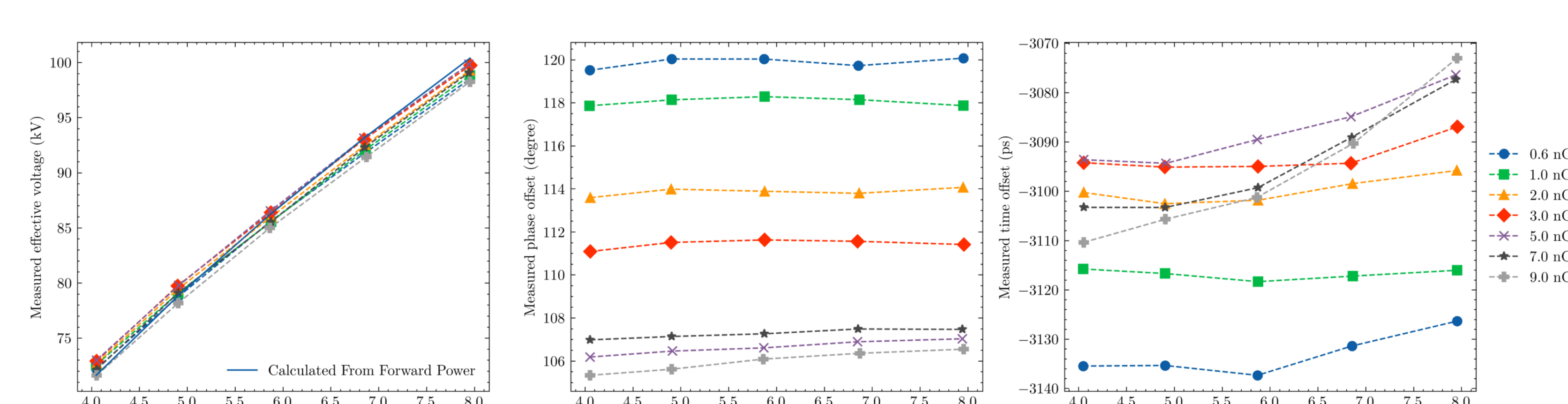

Fig.11 Experimental Results

Conclusion

An experimental method for calibrating the phase and amplitude of the SHB using two BPMs has been presented. For ToF extraction using the truncated averaging method, the single-particle model yielded accurate results without the need for further refinement. The combination of the truncated averaging method with the single-particle model proved to be both simpler and of greater practical significance compared with the particle-bunch model.

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