Bunch-by-bunch Profile Measurement During Beam Available Time

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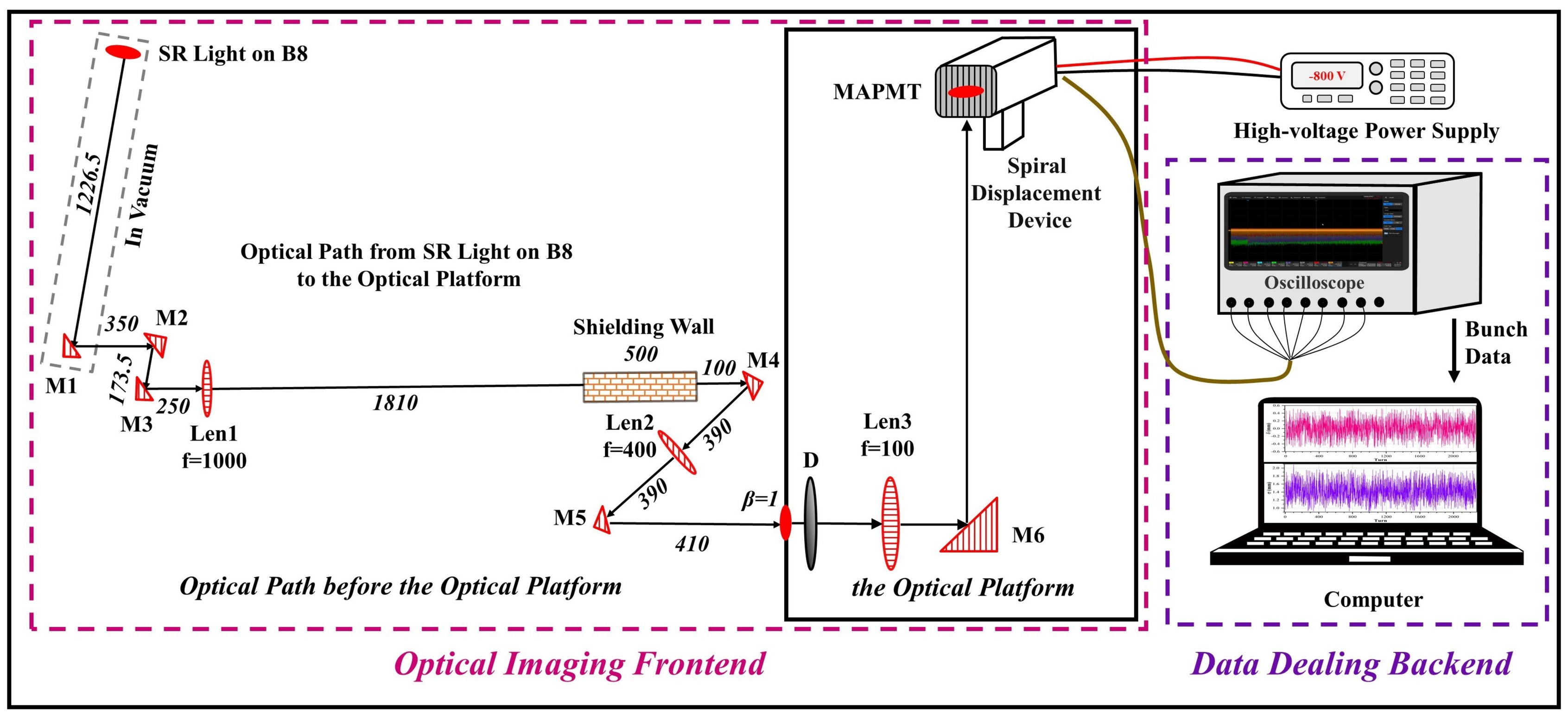
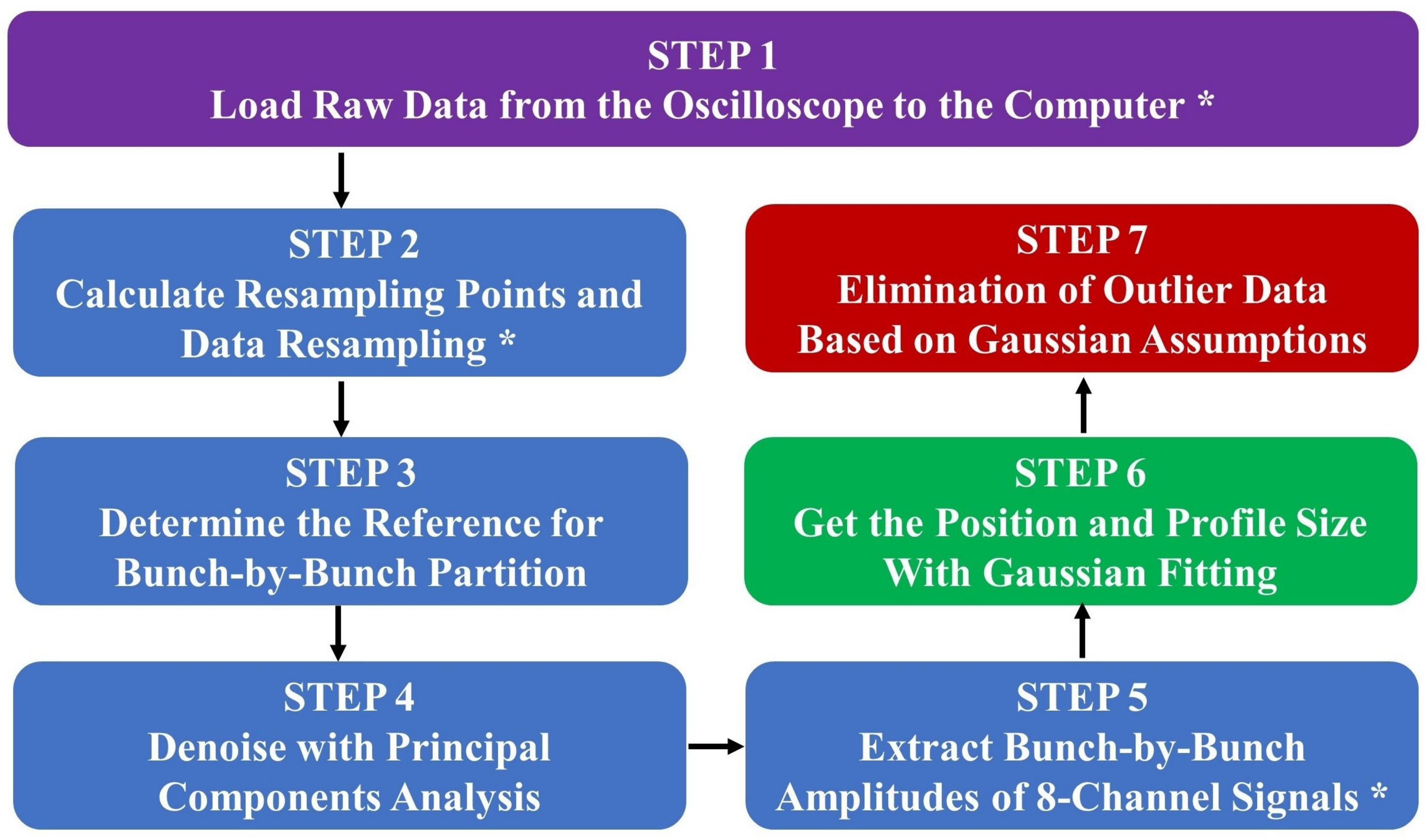
Background

A set of oscilloscope-based bunch-by-bunch profile measurement system is proposed and successfully implemented in the Hefei Light Source II (HLS-II) storage ring to measure the transverse positions and transverse profile sizes of bunches. This system includes an optical imaging frontend, a multi-channel photomultiplier tube for photoelectric conversion, and a high sampling rate oscilloscope for data recording, capable of measuring beam profile information during beam available period. By finely processing the collected data, the system can effectively recognize the dynamic characteristics of the beams and monitor the performance of the light source.

Layout of the System



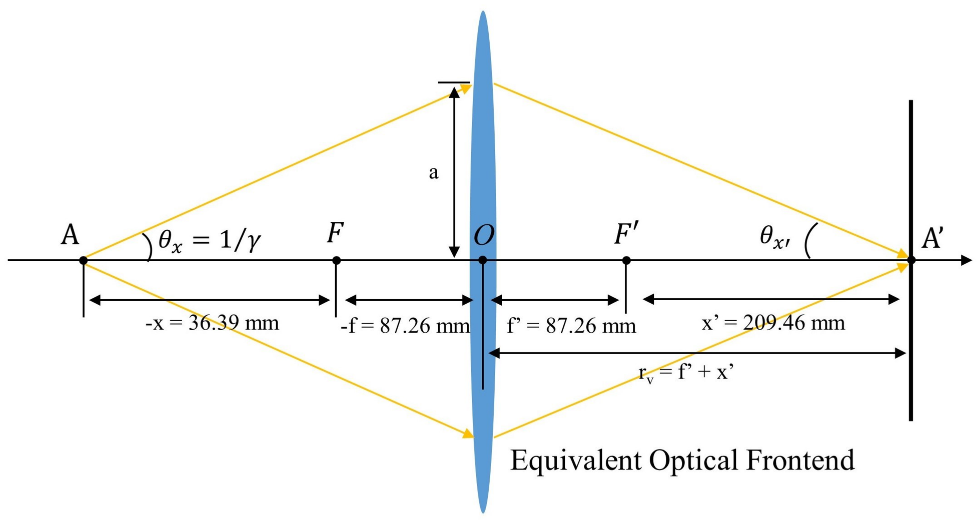
Processing Workflows



Detailed Description of these Processing Steps: 1) The program will load the raw bunch-by-bunch data of 8 channels with a recording time of 500us into the memory 2) The program calculates the number of turns of the data points captured in 500us according to the sampling rate of the oscilloscope and the RF frequency of the storage ring, and resamples the data according to the number of turns based on the method of spline interpolation. 3) Since the starting point of the oscilloscope sampling is random, it is necessary to perform convolution operation on the first two turns of the resampled data according to the sample function of the bunch filling distribution, and the calculated maximum value of the convolution operation is the starting point position of each turn of the data. 4) Resampled bunch-by-bunch data is reorganized into a matrix form to perform PCA algorithm 5) The signal peak vector $\bar{I}$ for each channel can be easily extracted by indexing in the resampled bunch-by-bunch signal 6) Gaussian Fitting calculates the transverse positions and transverse profile size of each bunch on the MAPMT image plane 7) Set up the assumption that the transverse positions and the transverse beam sizes of each bunch in the normal mode of the light source obey the Gaussian distribution. This assumption is used to remove the data outliers.

Measurement Error Analysis

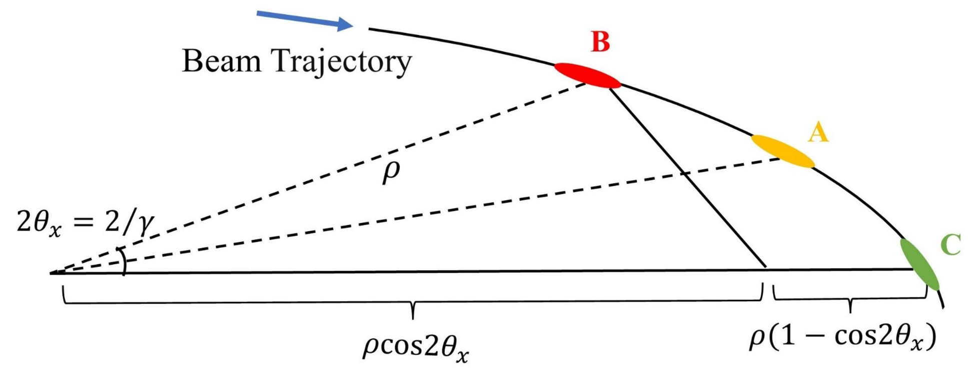
1) *Diffraction Error*



In the horizontal direction of the optical imaging system, the system can be viewed as a slit in a rectangular plane, and thus this error can be measured by the intensity distribution of diffraction from the slit. This diffraction error can be evaluated as:

$$se_{Diffaction} = \frac{\lambda r_v}{2a}$$

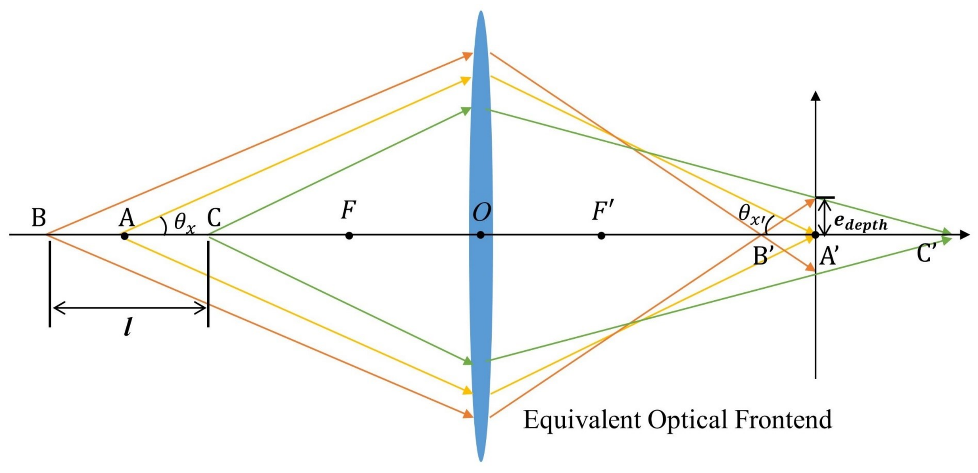
2) *Bending Error*



In the bending magnet, the orbit of the electron beam is curved at the horizontal plane. Therefore, the measured transverse beam profile is a superposition of a certain range of synchrotron light point sources. This bending error can evaluated as:

$$se_{Bending} = \rho(1 - cos2\theta_x) = 2\rho\theta_x^2$$

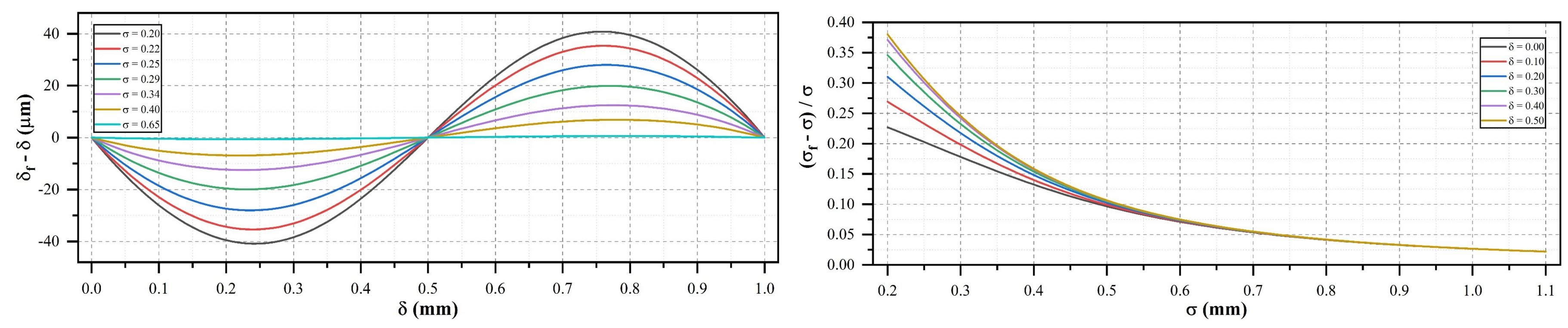
3) *Depth-of-field Error*



For the imaging system, the object along the optical axis direction can maintain a clear image in a certain axis range. While the optical frontend receives SR light from a section of the path in the bending magnet, equivalent to imaging when the object has a longitudinal depth. This depth-of-field error can be evaluated as:

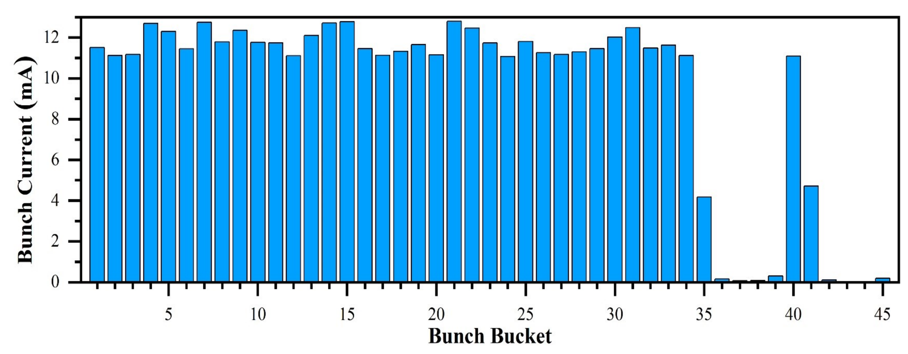
$$se_{Depth} = \tan\theta_{x'}\frac{l}{2}\beta^2 = \frac{1}{2}\rho\beta^2\theta_{x'}^2$$

4) *Gaussian-Fitting Error*

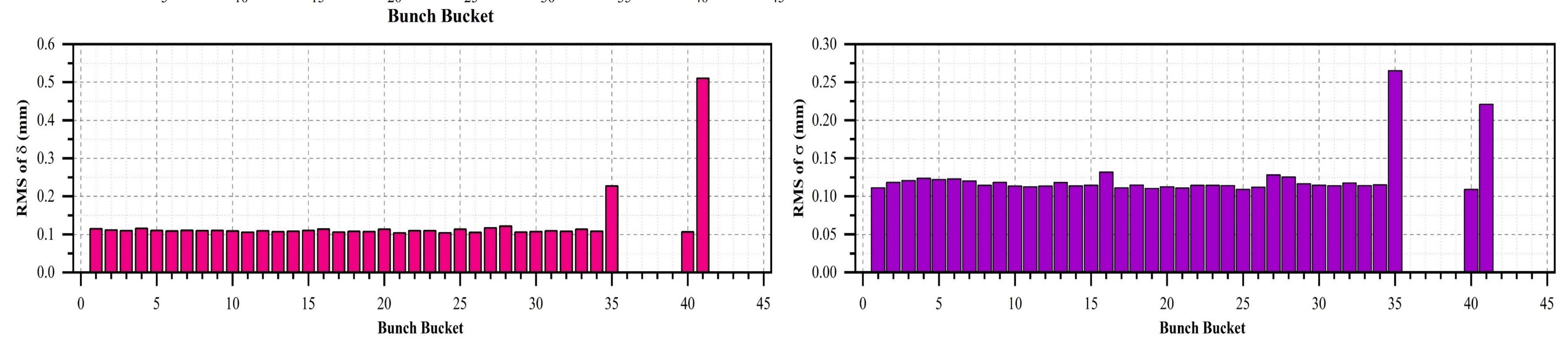


The beam profile information (δ_f, σf) obtained from the Gaussian fitting of the MAPMT multi-channel signals cannot be used directly, since difference exists between it and the actual transverse beam profile information (δ, σ) on the MAPMT imaging plane. While this systematic error can be completely eliminated with program simulation.

Measurement Results



The bunch filling pattern in the Hefei Light Source II (HLS-II) storage ring, where the bunches located at bucket 35 and bucket 41 are not completely filled.



It is clear that the bunches at bucket 35 and bucket 41 have larger RMS values than the rest of the bunches, which means that these two bunches fluctuate more violently when the light source is in the normal operation state. An intuitive explanation for this is that when a bunch passes through a RF cavity or other structure, it generates wake-files on the surrounding conductor surfaces or inside the medium. In the bunch trains, the wake-files generated by bunches lag behind and affect subsequent bunches, and this effect is particularly pronounced for the trailing bunch in the bunch train.

Main References

[1] Wu, Ruizhe, et al. "One in-situ extraction algorithm for monitoring bunch-by-bunch profile in the storage ring." Journal of Physics: Conference Series. Vol. 2700. No. 1. IOP Publishing, 2024.

[2] Wu, Ruizhe, et al. "A Computing Module for Speeding up Bunch-by-Bunch Measurement of Transverse Positions and Transverse Profiles Within Injection Period." Journal of Instrumentation 17.11 (2024): P11001.

[3] Quanting, Liang. *Physical Optics*. Electronic Industry Press, 2022, p. 166. ISBN 978-7-121-20441-8.