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Simulation and Experiments of Transverse Emittance Measurements with Slit scan and Quadrupole scan at ELBE SRF Gun

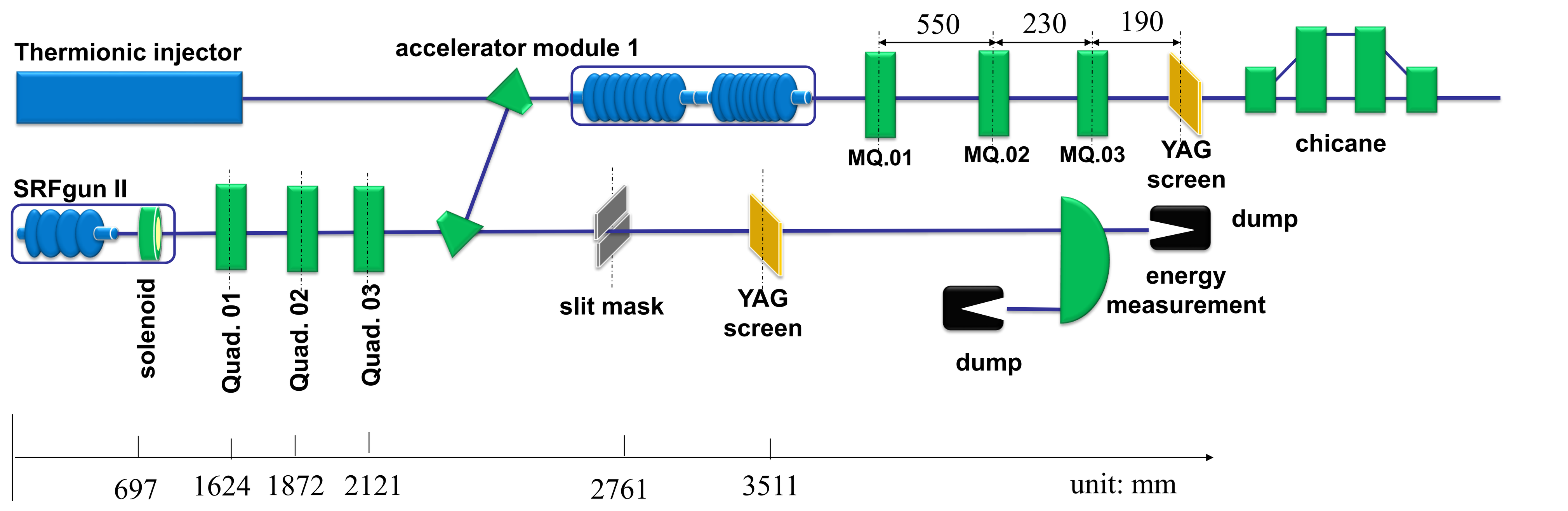
HZDR HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

S.Ma † 1), A. Arnold 1), P.Murcek1), A .Ryzhov 1),R.Steinbrück1), J. Schaber 1,2), J.Teichert 1), R. Xiang 1)
1) Helmholtz-Zentrum Dresden-Rossendorf, Germany, 2) Technische Universität Dresden, Germany

Introduction

The radiation source ELBE (Electron Linac for beams with high Brilliance and low Emittance) delivers multiple secondary beams, both electromagnetic radiation and particles. To measure beam emittance effectively before user time, the fast and accurate methods have been developed, the continue moving slit scan for high bunch charge and the quadrupole scan for low bunch charge. In this poster the errors from the methods and quadrupole calibration will be discussed in simulation and experiments, and give the experiments results.

Experimental layout

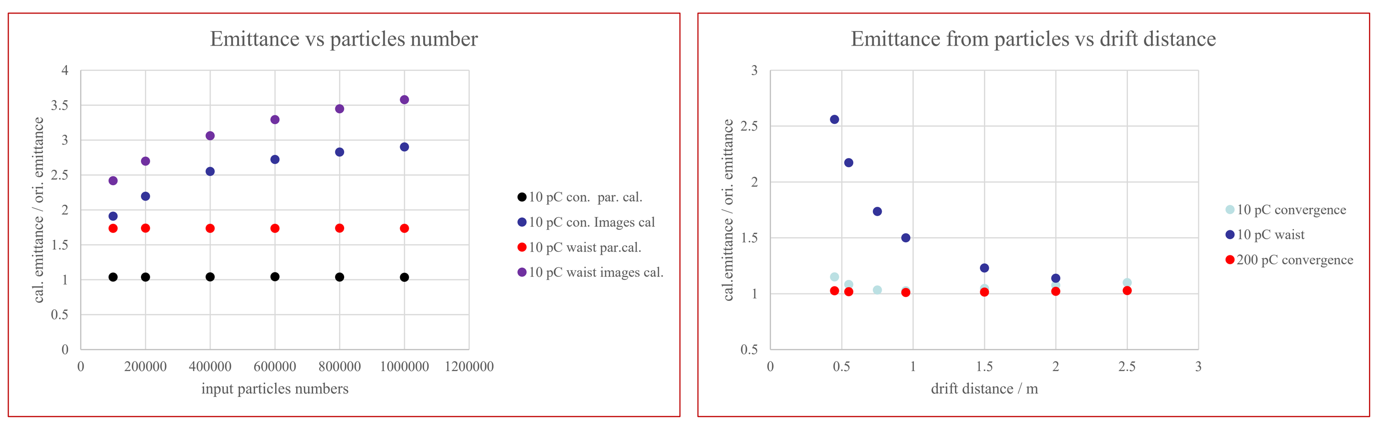


Transverse Emittance Measurement Simulation and Experiments

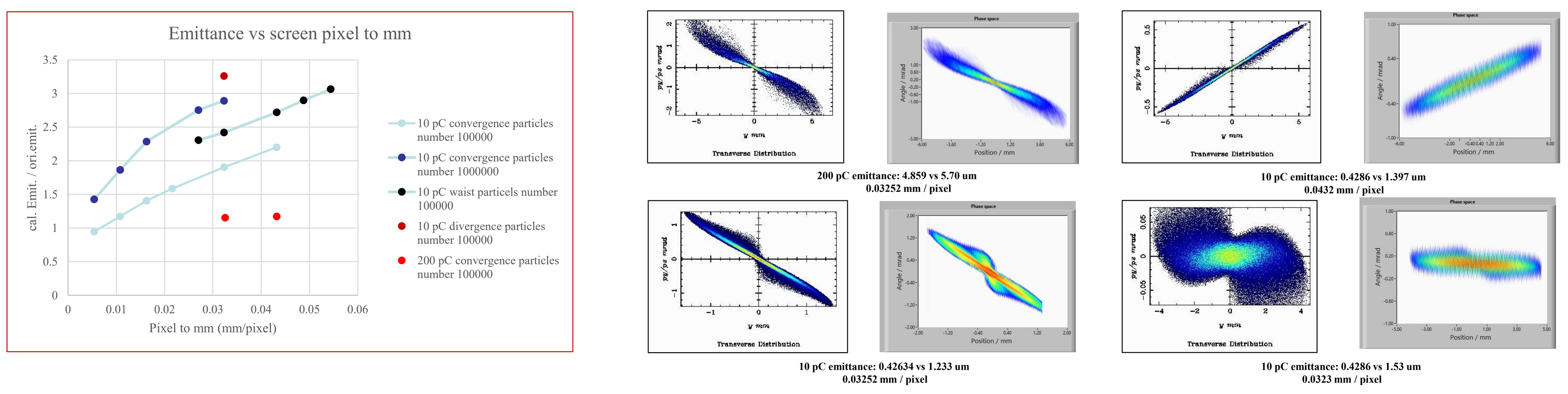
Slit-scan Astra simulation

Steps:

1. Total particles number: 100,000 to 1,000,000; bunch charge 10 pC and 200 pC; beam energy 4.4 MeV;
2. Cut beam into beamlet, slit width 100 um, step 10 um;
3. Every beamlet particles are used as input particles to the next drift space simulation(slit to screen);
4. Record and plot every beamlet particles position at screen position as images from camera;
5. Calculate and rebuild beam phase space at slit position ;
6. Compare calculation results with ideal results.

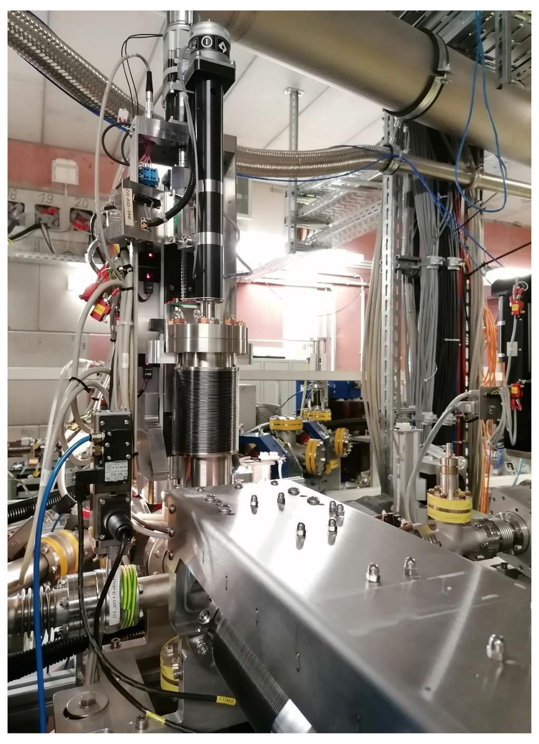


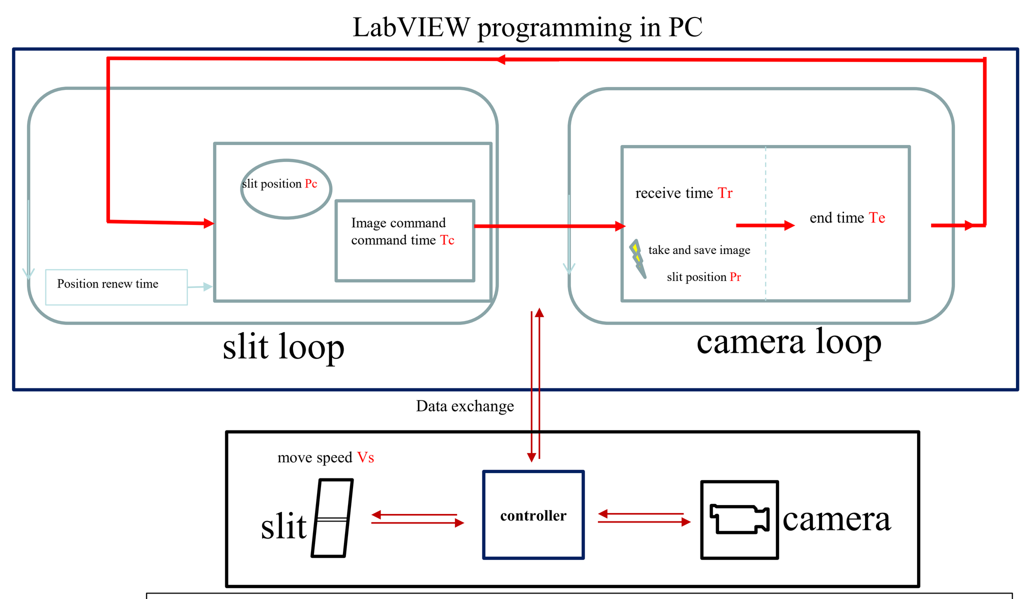
Conclusions:
From the simulation, for different beam status, the error of emittance from slit scan is different. Converged beam gives smaller error than waist and diverged beam at slit position.

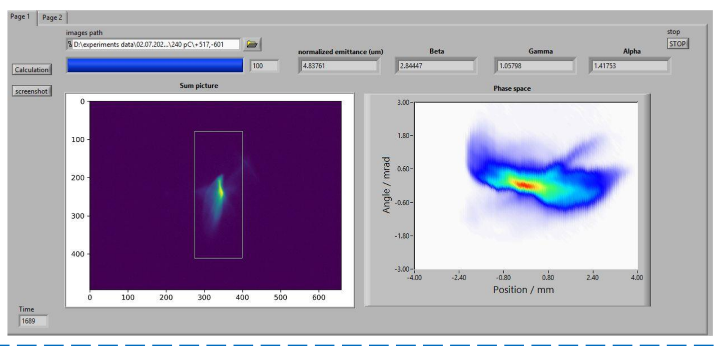


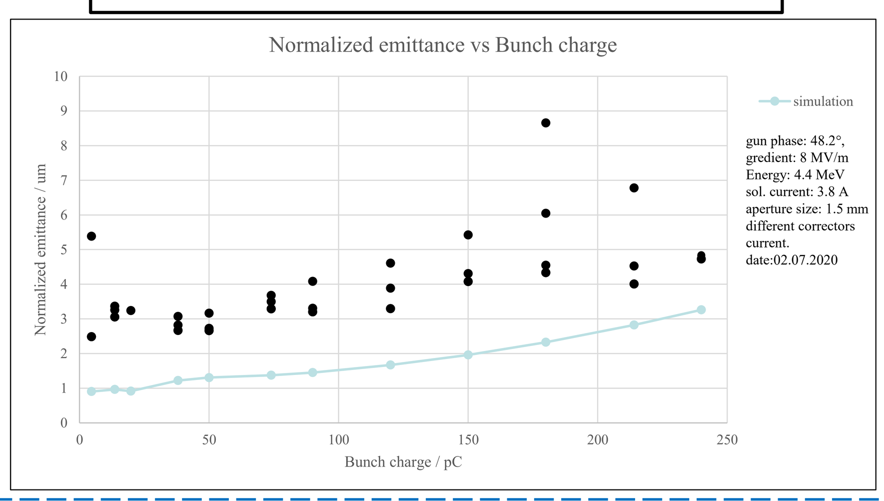
Fast Slit-scan experiment

In fast slit-scan experiment, the speed of slit is adjustable from 0 to 2 mm/s. The frame rate of camera is up to about 75 fps. Movement loop and image capture loop are parallel. Parallel algorithm is used in images and data processing. It will take around one minute for each measurement.





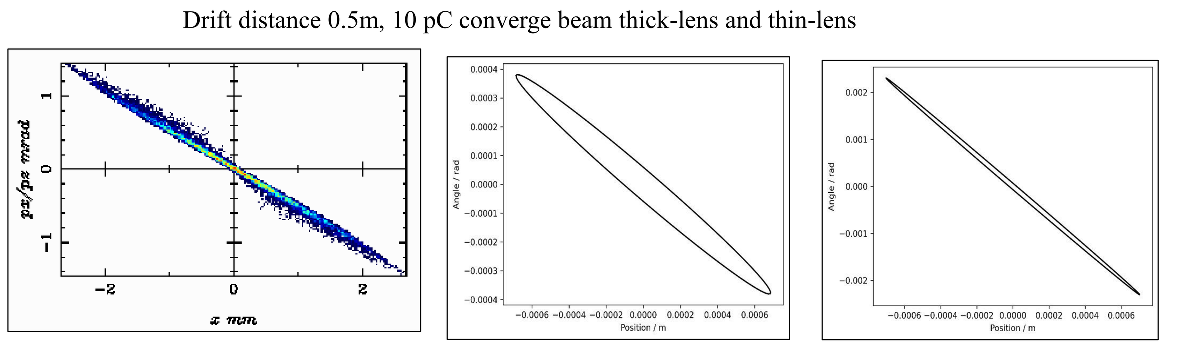




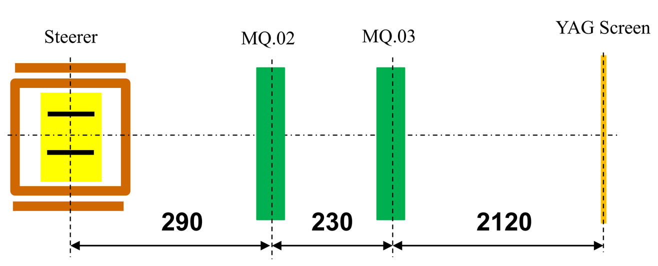
Quadrupole scan simulation and calibration

Quadrupole scan is a traditional emittance measurement method depending on linear beam dynamics. This means for space charge dominated beam, it will have larger error. To simplify calculations, the thin-lens approximation is used during data processing ignoring the approximation condition. Sometimes this will result in that the fitting parameters are unstable which maybe make calculated emittance is a complex. This will happen when the scale of points is larger than the scale of the minimum point in simulation cases. Using thick-lens can avoid this condition. However it still has errors which depend on the drift distance. From phase space ellipse, thick-lens is more similar to the real.

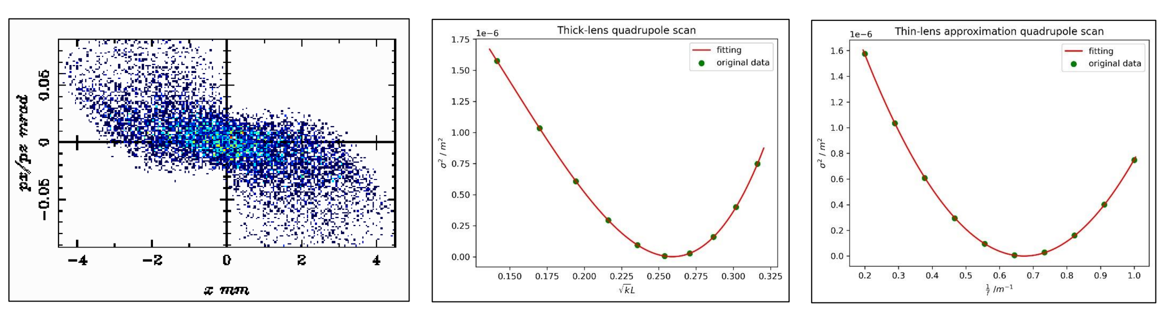
Drift distance 0.5m, 10 pC converge beam thick-lens and thin-lens



Quadrupole calibration

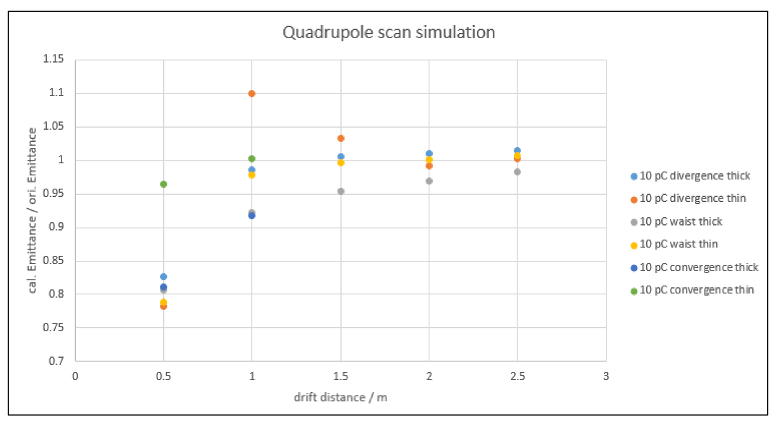


Thin-lens approximation invalid example: 10 pC waist beam at quadrupole station, drift distance is 1.5 m. original emittance: 0.431um, thick-lens: 0.3865 um, thin-lens: nan.



$$\begin{pmatrix} x_s \\ x_s' \end{pmatrix} = \begin{pmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{pmatrix} \begin{pmatrix} x_0 \\ x_0' \end{pmatrix}$$

$$R_{12} = \frac{dx_s}{dx_0'}$$

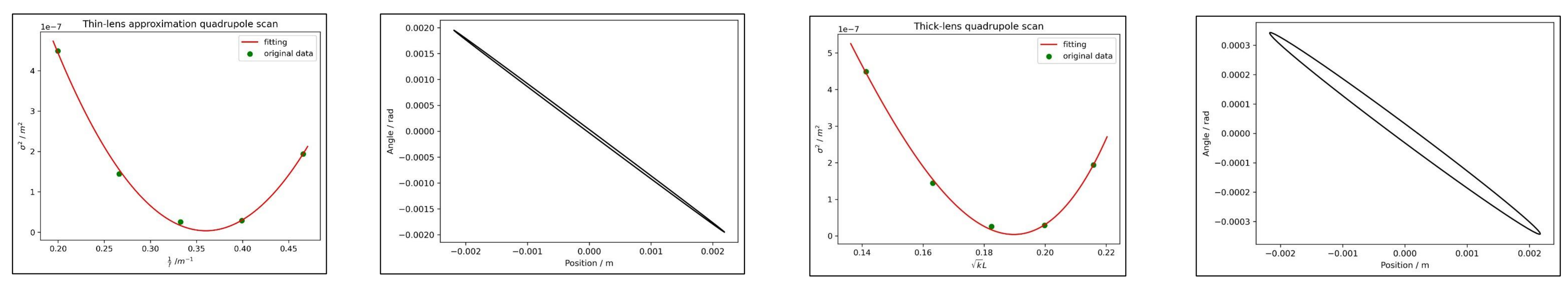


Thin-lens approximation and thick-lens methods both have error when drift distance smaller than 1.0 meter. Thin-lens approximation method shows highly depending on the symmetric of the points data in low bunch charge. Thick-lens is much more reliable, but still has error especially in short drift distance. This error comes from fitting system error.

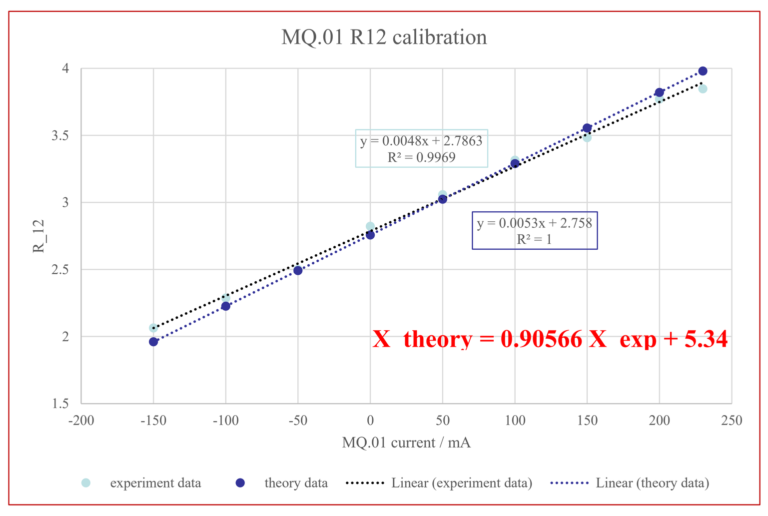
Quadrupole scan experiments

SRF gun gradient: 8.01 mV/m; gun phase: 50°; beam energy: 4.4 MeV; drift distance: 1.887 m (Quad.01-YAG screen); bunch charge: ~20 pC.

	Thin-lens before calibration	Thick-lens before calibration	Thin-lens after calibration	Thick-lens after calibration
Horizontal emittance (um)	0.6158 ± 0.064	0.607 ± 0.024	0.68 ± 0.071	0.668 ± 0.035
Vertical emittance (um)	0.6932 ± 0.073	0.654 ± 0.017	0.765 ± 0.081	0.723 ± 0.025



Horizontal emittance without quad. calibration



Conclusion:
From the experiment emittance results, thick-lens can only decrease the emittance about 3% . However, it has large influence to the phase space ellipse. The error from the quadrupole will increase the emittance results, about 10% in this case, which is similar to the current error between experiment and theory.

Acknowledgement

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Contact: Shuai Ma, Institute of Radiation Physics, Radiation Source ELBE. Email: s.ma@hzdr.de