Quadrupole Scan Transverse Emittance Measurements of SRF Gun at ELBE

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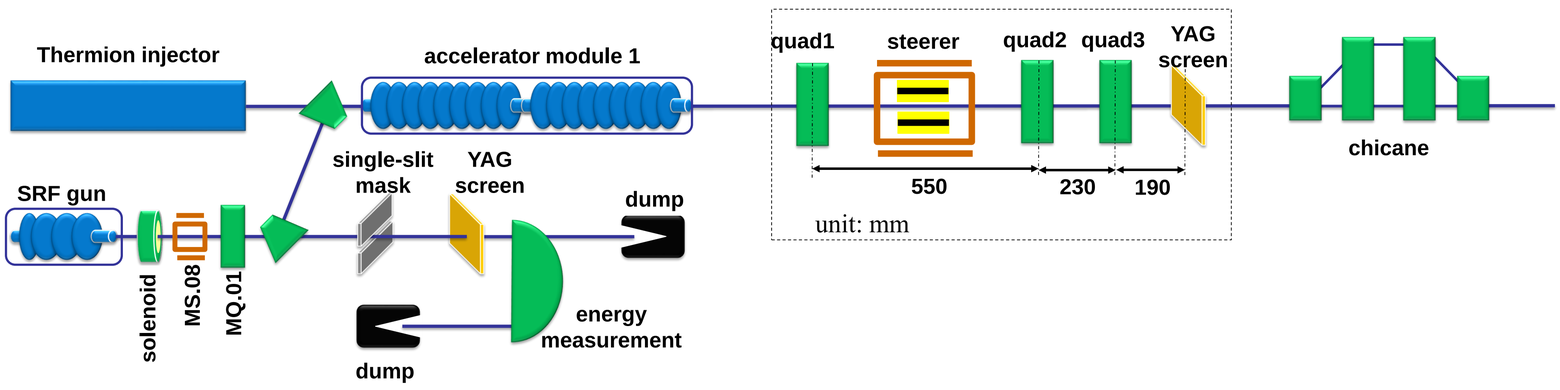
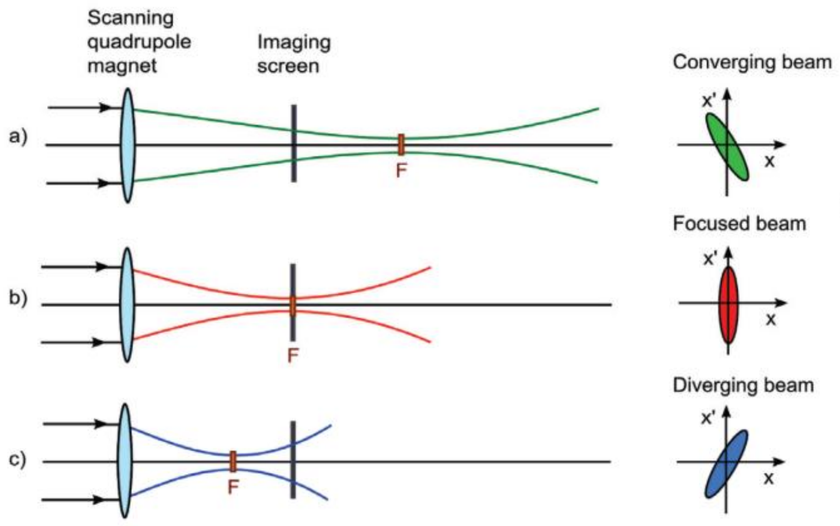
Beam line layout



- mode: CW
- bunch charge: 60 pC
- Gun gradient = 7.142 MV / m
- Cavity1 gradient = 8.023 MV / m
- Cavity2 gradient = 4.522 MV / m
- Energy = 16.116 MeV
- Bunch length ~ 2 ps
- Energy spread: 0.2%
- DC voltage: -5 kV

Transverse Emittance Measurement

Quad-scan method



- change the quadrupole current
- photograph the images on screen
- integrate the distribution and calculate beam rms sizes
- fit beam rms sizes as quadrupole strength

$$\Sigma = \begin{pmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{21} & \sigma_{22} \end{pmatrix} \qquad \Sigma^s = M\Sigma^q M^T$$

$$\sigma_{11} = \langle x_i^2 \rangle = \epsilon\beta,\ \sigma_{22} = \langle x'^2_i \rangle = \epsilon\gamma,$$
$$\sigma_{12} = \sigma_{21} = \langle x_i x'_i \rangle = -\epsilon\alpha.\ \langle x_i^2 \rangle$$

$$\epsilon = \det(\Sigma) = \sqrt{\sigma_{11}\sigma_{22} - \sigma_{12}^2}$$

$$\epsilon_n = \beta\gamma\epsilon$$

Transport matrix

Converge

$$M = \begin{bmatrix} 1 & d \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \cos(\sqrt{k}l) & \frac{1}{\sqrt{k}}\sin(\sqrt{k}l) \\ -\sqrt{k}\sin(\sqrt{k}l) & \cos(\sqrt{k}l) \end{bmatrix}$$

$$\sigma_{11}^s = \left(\sigma_{11}^q + d^2\sigma_{22}^q + 2d\sigma_{12}^q\right)cos^2\left(\sqrt{k}l\right) + \frac{-2d\sigma_{11}^q - 2d^2\sigma_{12}^q}{l}\left(\sqrt{k}l\right)\sin\left(\sqrt{k}l\right)\cos\left(\sqrt{k}l\right) + \frac{d^2\sigma_{11}^q}{l^2}(\sqrt{k}l)^2 sin^2\left(\sqrt{k}l\right) + \frac{l^2\sigma_{22}^q}{(\sqrt{k}l)^2}sin^2\left(\sqrt{k}l\right) + \left(2d\sigma_{22}^q + 2\sigma_{12}^q\right)l \cdot \frac{1}{\sqrt{k}l}\sin\left(\sqrt{k}l\right)\cos\left(\sqrt{k}l\right) + \left(-2d\sigma_{12}^q\right) sin^2\left(\sqrt{k}l\right)$$

Diverge

$$M = \begin{bmatrix} 1 & d \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \cos h(\sqrt{k}l) & \frac{1}{\sqrt{k}}\sin h(\sqrt{k}l) \\ \sqrt{k}\sinh(\sqrt{k}l) & \cos h(\sqrt{k}l) \end{bmatrix}$$

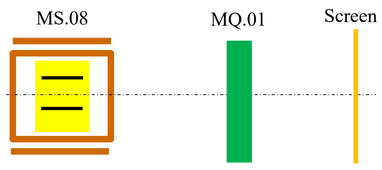
$$\sigma_{11}^s = \left(\sigma_{11}^q + d^2\sigma_{22}^q + 2d\sigma_{12}^q\right)cosh^2\left(\sqrt{k}l\right) + \frac{2d\sigma_{11}^q + 2d^2\sigma_{12}^q}{l}\left(\sqrt{k}l\right)\sin h\left(\sqrt{k}l\right)\cosh\left(\sqrt{k}l\right) + \frac{d^2\sigma_{11}^q}{l^2}(\sqrt{k}l)^2 sinh^2\left(\sqrt{k}l\right) + \frac{l^2\sigma_{22}^q}{(\sqrt{k}l)^2}sinh^2\left(\sqrt{k}l\right) + \left(2d\sigma_{22}^q + 2\sigma_{12}^q\right)\frac{l}{\sqrt{k}l}\sin h\left(\sqrt{k}l\right)\cos h\left(\sqrt{k}l\right) + 2d\sigma_{12}^q sinh^2\left(\sqrt{k}l\right)$$

Thin-approximation

$$M = \begin{pmatrix} 1 & d \\ 0 & 1 \end{pmatrix}\begin{pmatrix} 1 & 0 \\ \mp kl & 1 \end{pmatrix}$$

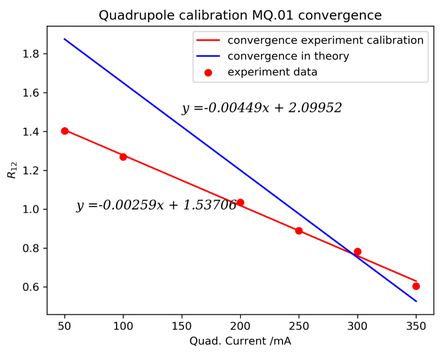
$$\sigma_{11}^s = \left(\sigma_{11}^q d^2 l^2\right)k^2 + \left(2dl\sigma_{11}^q \mp 2d^2 l\sigma_{12}^q\right)k + \sigma_{11}^q + 2d\sigma_{12}^q + d^2\sigma_{22}^q$$

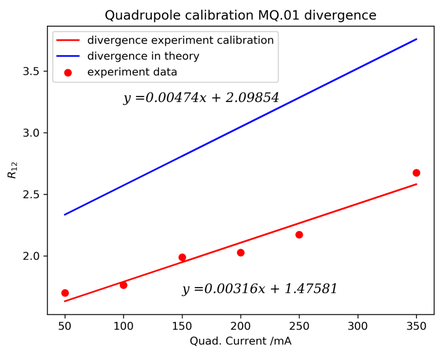
Quadrupole calibration

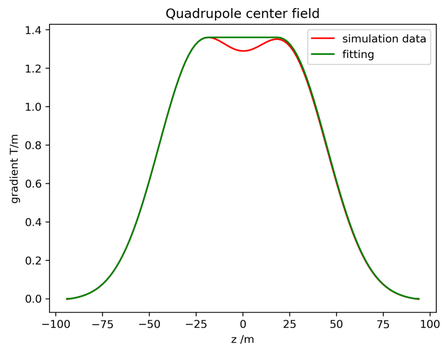


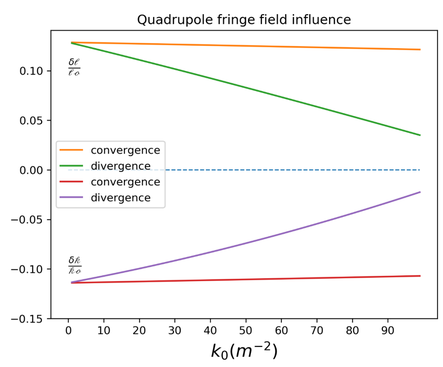
$$\begin{pmatrix} x_s \\ x'_s \end{pmatrix} = \begin{pmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{pmatrix}\begin{pmatrix} x_0 \\ x'_0 \end{pmatrix} \qquad R_{12} = \frac{dx_s}{dx'_0}$$

In theory, thin-approximation $\quad R_{12} = L_1 + L_2 - klL_1L_2$







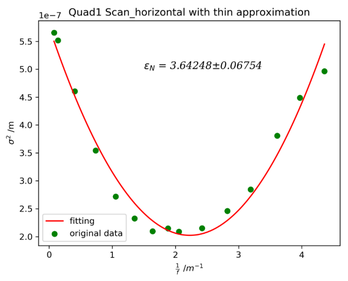


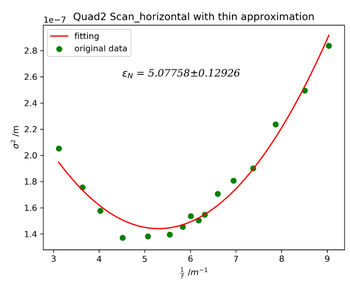
$$l_0 = \frac{\int kdz}{k_0}$$

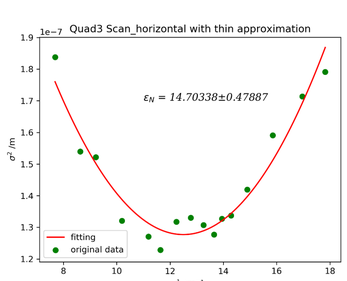
$$\delta l = l_{eff} - l_0 \qquad \delta k = k_{eff} - k_0$$

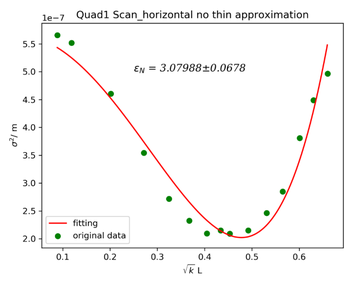
Emittance results

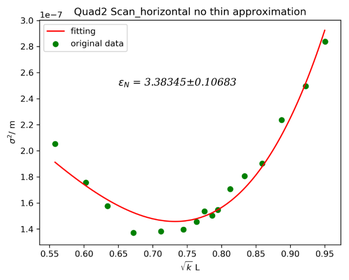
	ϵ_n(π.mm.mrad) thin-approximation	ϵ_n(π.mm.mrad) without approximation
Quad.1	3.642±0.068	3.080±0.068
Quad.2	5.078±0.129	3.383±0.107
Quad.3	14.703±0.479	5.985±0.240

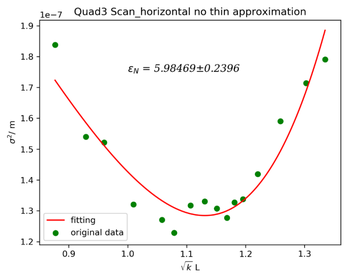












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Reference:
[1] Wiedemann, Helmut. Particle accelerator physics. Springer, 2015.
[2] Anderson, S. G., et al. Physical Review Special Topics-Accelerators and Beams 5.1 (2002): 014201.
[3] Lu, Pengnan. Optimization of an SRF Gun for high bunch charge applications at ELBE. Diss. Saechsische Landesbibliothek-Staats-und Universitaetsbibliothek Dresden, 2017.
[4] Vennekate, Hannes. "Emittance Compensation for SRF Photoinjectors." (2017).

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