MOPMB086

Development of Non-Destructive Beam Envelope Measurements in SRILAC with Low Beta Heavy Ion Beams Using BPMs

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Related paper for SRF' 23:

K. Yamada *et al.*, "Operational Experience for RIKEN Superconducting Linear Accelerator", MOIXA04

K. Ozeki *et al.*, "Present Status of Riken Power Couplers forSRILAC" , MOPMB086

N. Sakamoto *et al.*, "Degeneration and Recovery of Cavity Performance in SRILAC Cryomodules at RIKEN RI-Beam Factory", WEPWB085

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Introduction: B(E)PMs in Superconducting RIKEN LINAC (SRILAC)

The Superconducting RIKEN LINAC (SRILAC) has been providing heavy ion beams of a few pμA for the synthesis of new superheavy elements [1] since June 2020, utilizing 10 superconducting quarter-wavelength resonators (SC-QWRs) [2]. Although the beam supply has been stable, it is crucial to measure and control the beam dynamics in the SRILAC to increase the beam intensity up to 10 puA.

⇔ Beam has been tuned only by monitoring the beam center using Beam Energy Position Monitors (BEPMs) [3] and the reactions of vacuum monitors.

In this work, we report the development of new method to estimate beam envelopes using quadrupole moments deduced from BEPMs signals [4].

wire scanner (profile monitor / PF)
- beam position
- beam profile
- ~~beam energy~~
- low intensity / <u>destructive</u>

dust production

only used outside of SRILAC

Beam Energy Position Monitors (BEPMs)
- beam position
- ~~beam profile~~
- beam energy
- <u>non-destructive</u>

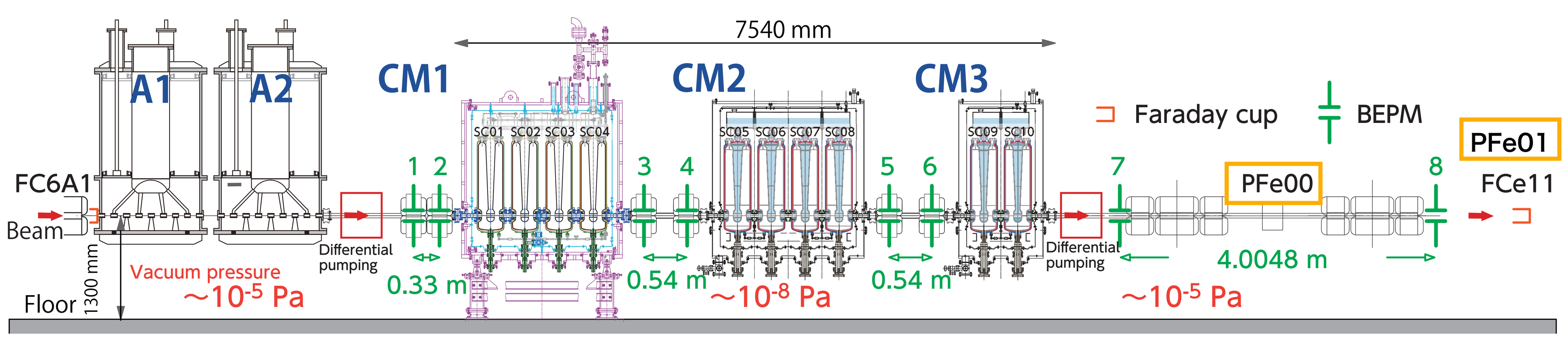
No dust production

used inside SRILAC

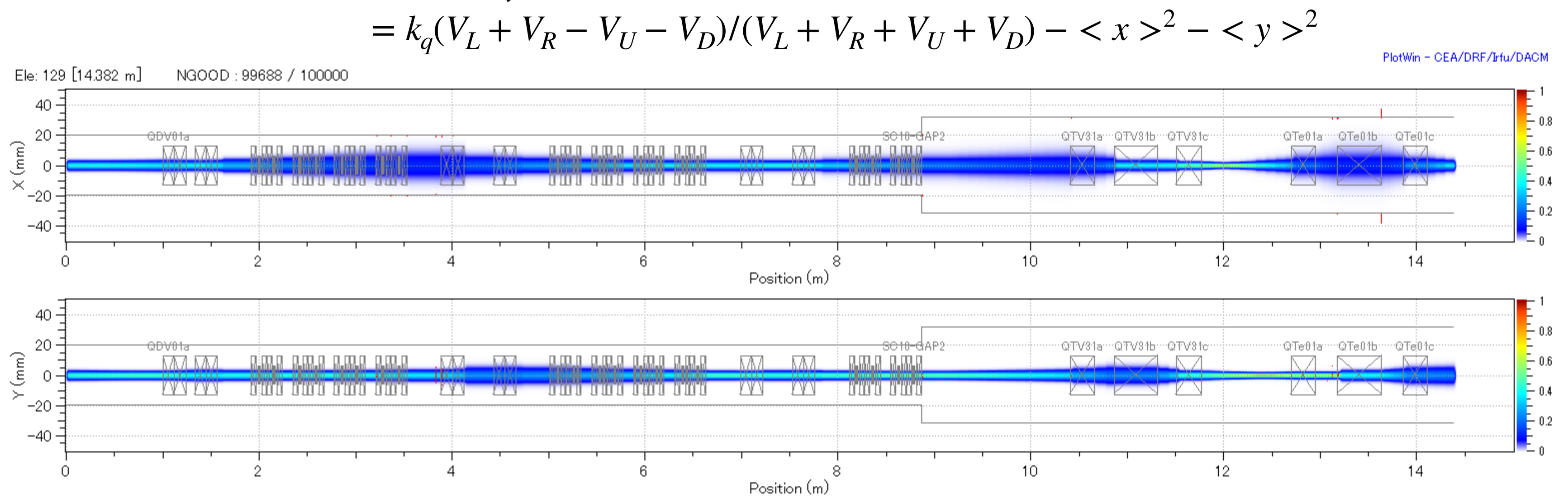
+ Transfer matrix M = **Beam ellipse parameters**

$$\begin{pmatrix} Q_1 \\ Q_2 \\ \vdots \\ Q_8 \end{pmatrix} = \begin{pmatrix} M_x(1|0)_{11}^2, -2M_x(1|0)_{11}M_x(1|0)_{12}, M_x(1|0)_{12}^2, -M_y(1|0)_{11}^2, \cdots \\ M_x(2|0)_{11}^2, -2M_x(2|0)_{11}M_x(2|0)_{12}, M_x(2|0)_{12}^2, -M_y(2|0)_{11}^2, \cdots \\ \vdots \\ M_x(8|0)_{11}^2, -2M_x(8|0)_{11}M_x(8|0)_{12}, M_x(8|0)_{12}^2, -M_y(8|0)_{11}^2, \cdots \end{pmatrix} \begin{pmatrix} \epsilon_x\beta(0)_x \\ \epsilon_x\alpha(0)_x \\ \epsilon_x\gamma(0)_x \\ \epsilon_y\beta(0)_y \\ \epsilon_y\alpha(0)_y \\ \epsilon_y\gamma(0)_y \end{pmatrix}$$

$$Q = \sigma_x^2 - \sigma_y^2 = k_q(V_L + V_R - V_U - V_D)/(V_L + V_R + V_U + V_D) - \langle x \rangle^2 - \langle y \rangle^2$$



Schematic view of Superconducting RIKEN LINAC (SRILAC)



Beam dynamics simulation based on **BEPM-measured phase ellipse** (by TraceWin)

Bias on Q evaluation: low β effect

There is **"bias"** to calculate Q in both of data and CST simulations as

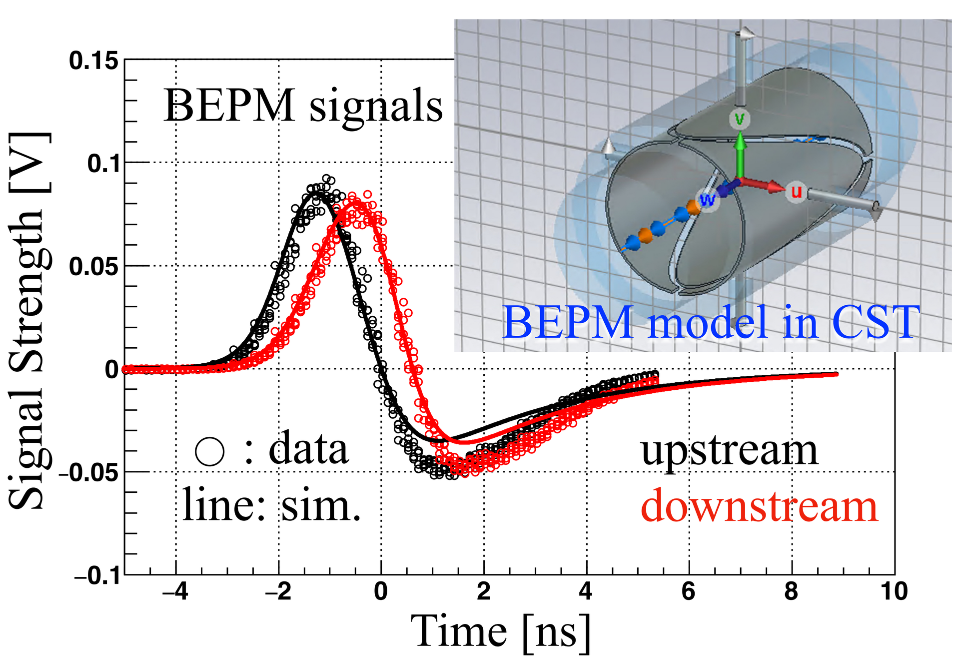
$$V_{upstream} = b \times V_{downstream}$$
$$b : 1.03 \sim 1.06$$

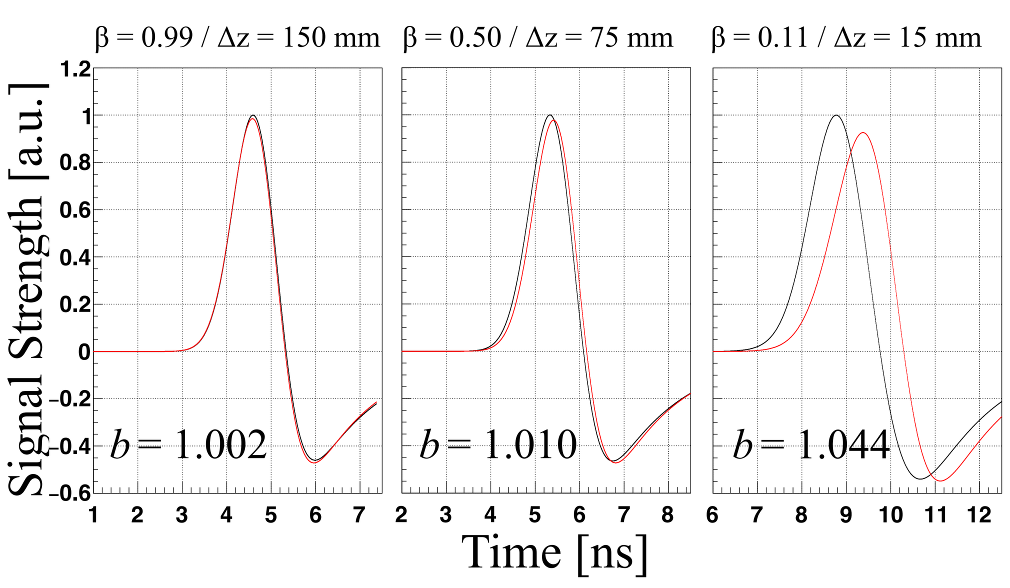
even for $\sigma_x \fallingdotseq \sigma_y$ condition.
The effect depends on β and Δz, and does not depend on beam transverse positions according to CST simulation.
→ It is critical for our case.

$$\beta : 0.09 \sim 0.12$$
$$\Delta z : 5 \sim 15 \text{ mm (1 rms)}$$

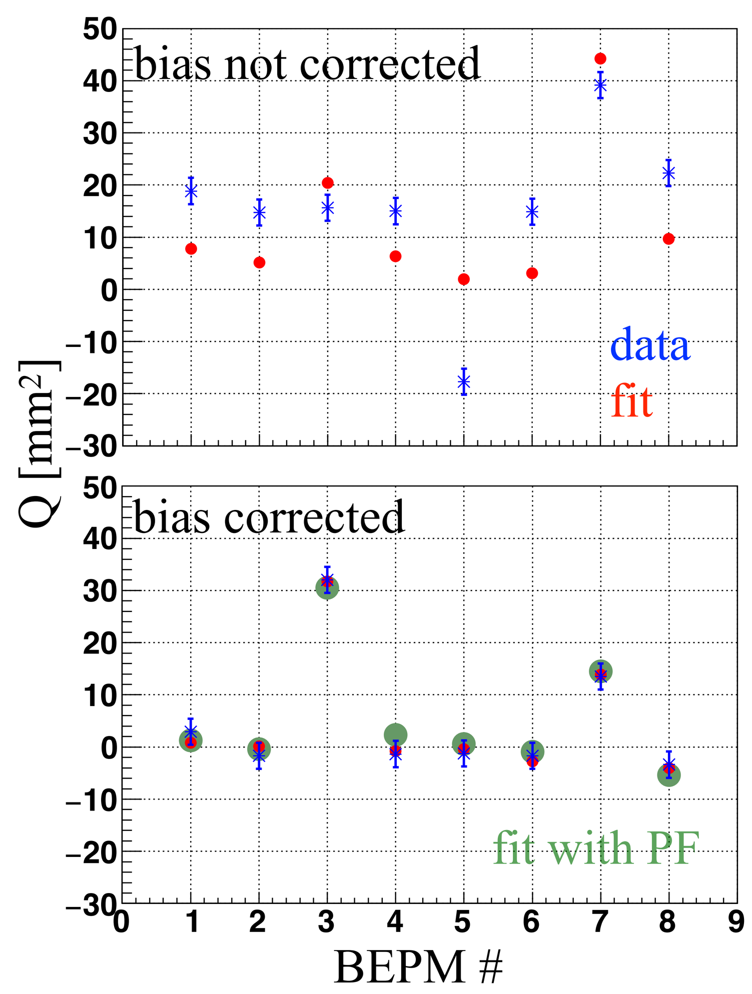
The bias factors b are determined for two type of BEPM to reproduce the Q-scan measured emittance (2023 Apr. 14th) and ambiguities of b are taken into the error of Q.

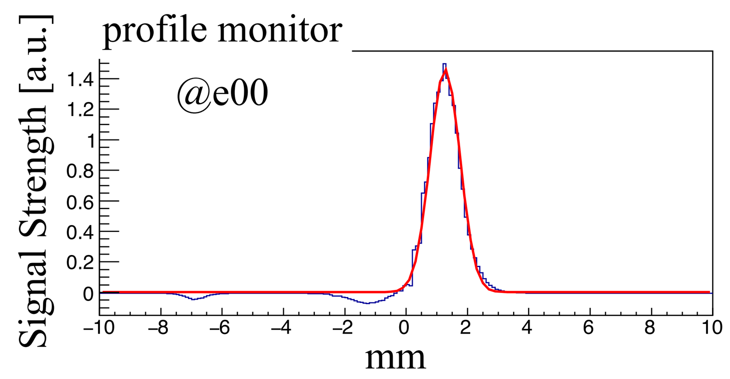
b_A for BEPM type A (ΔL = 50 mm): 1.060
b_B for BEPM type B (ΔL = 60 mm): 1.044





Phase ellipse measurement with BEPMs





8 BEPMs are utilized to estimate phase ellipse for actual data. To increase sensitivity for absolute σ_x, σ_y, 1 profile monitor data (horizontal / vertical) are added for the analysis. After bias correction and adding PF data, estimated phase ellipses seem to be more "reasonable".

Adding profile monitor data:

<u>advantage</u>
- improve sensitivity for absolute value of ε_h, ε_v

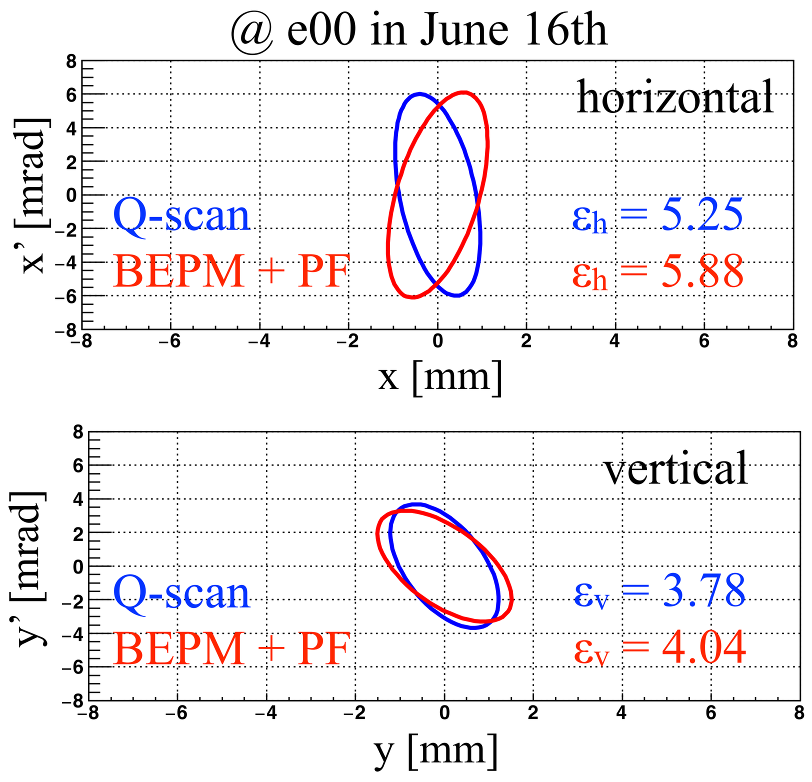
<u>disadvantage</u>
- require destructive measurement

→ one measurement w/o changing magnetic field still much easier than Q-scan method

	ε_h	ε_v	χ^2/ndf
bias not corrected	3.16	0	163/2
bias corrected	6.72	2.64	1.67/2
bias corrected + profile monitor	**5.88**	**4.04**	**5.57/4**

Numerical comparison with Q-scan method

Estimated phase space @ e00 in June 16th



Obtained phase ellipses at e00 are compared with these by Q-scan measurement [5].

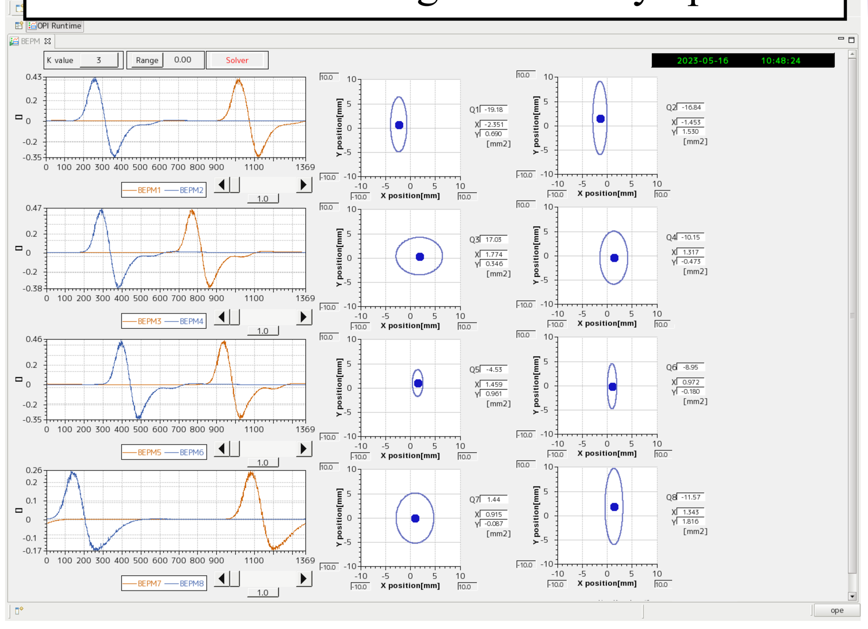
- ε_h, ε_v have changed from "calibration data" for bias factors. (**ε_h = 4.8 / ε_v = 7.1** in Apr. 14th)
- Shape of phase spaces are also agrees well. Discrepancy of α_h corresponds to ~ 15 cm.
- Phase ellipses estimated from BEPM + PF data agree with Q-scan results in ~10% accuracy!!

Summary

- Developed a new approach using BEPM signals to estimate beam dynamics in SRILAC.
- Found and corrected a bias on the signals from BEPMs for low beta particles.
- Successfully reproduced the phase ellipse observed through the Q-scan method.
- Integrated visualizations of estimated phase ellipses into our daily monitoring systems.
- Planning to collect additional data for further validation and incorporation of the method into routine operations for improved beam tuning precision.

Finally, we are grateful to Professor T. Toyama of KEK/J-PARC for fruitful discussions.

Monitor for BEPM signals in daily operation



Reference

[1] H. Sakai *et al.*, Eur. Phys. J. A, vol. 58. pp.238 (2022).
[2] K. Yamada *et al.*, in Proc. SRF'21, paper MOOFAV01(2021).
[3] T. Watanabe *et al.*, in Proc. IBIC'20, paper FRAO04 (2020).
[4] R. H. Miller *et al.*, in Proc. HEAC'83, pp. 603--605 (1983).
[5] T. Nishi *et al.*, in Proc. HB'21, paper THBC1 (2021).