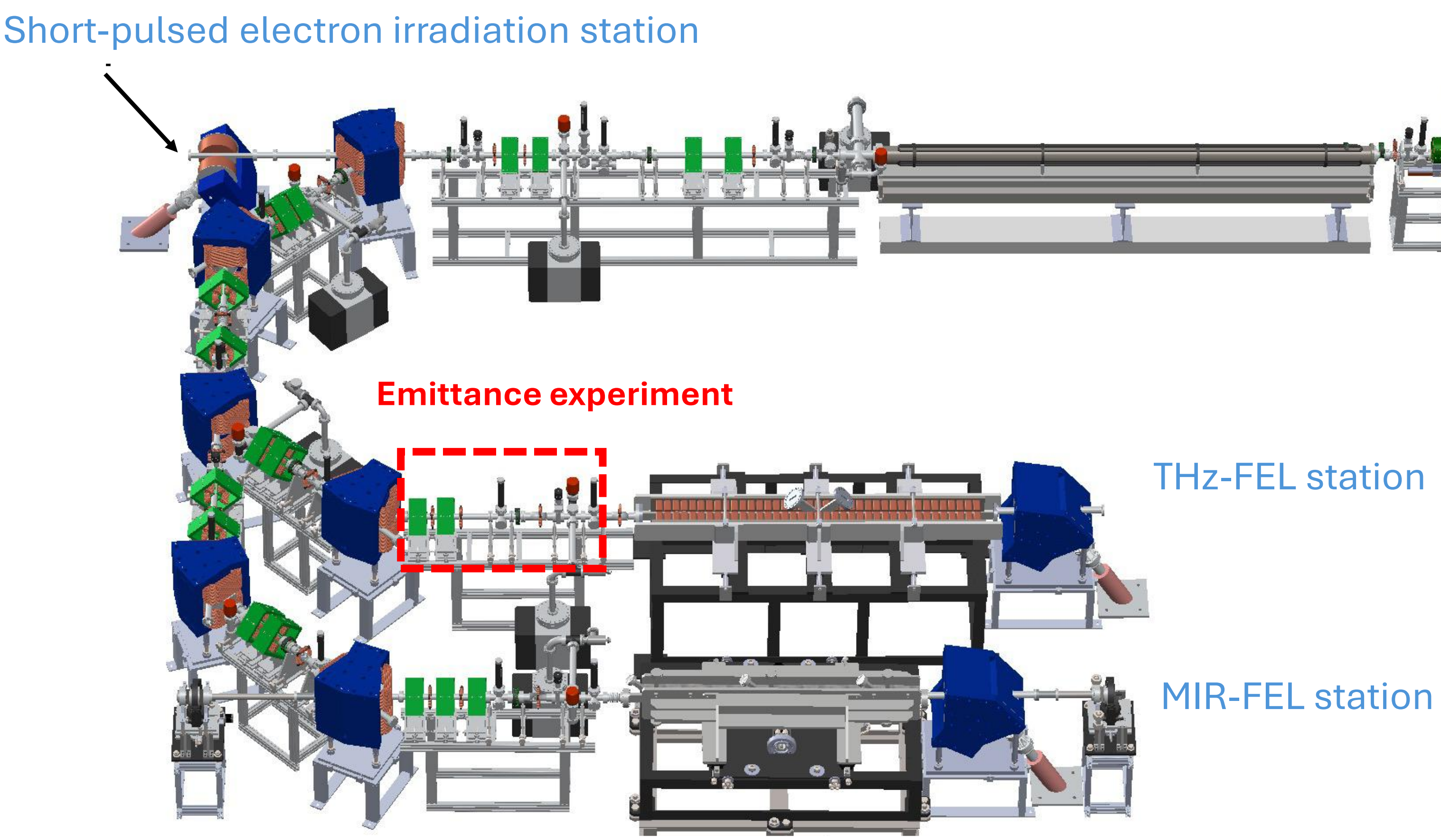
Simulations of electron beam dynamics and development of the experimental setup to analyze normalized emittance

Waralak Jaipang

Chiang Mai University

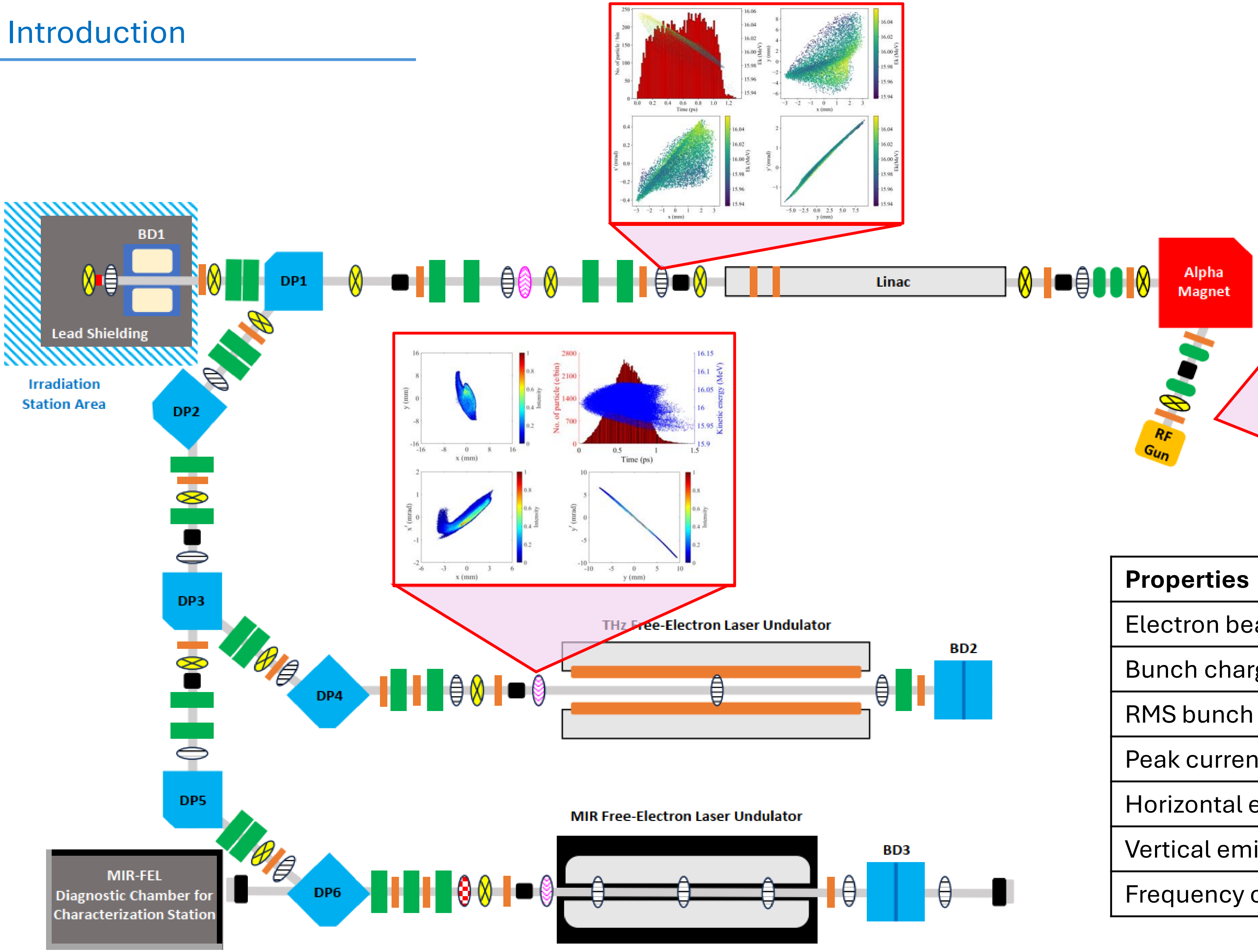
The PBP-CMU Electron Linac Laboratory (PCELL)

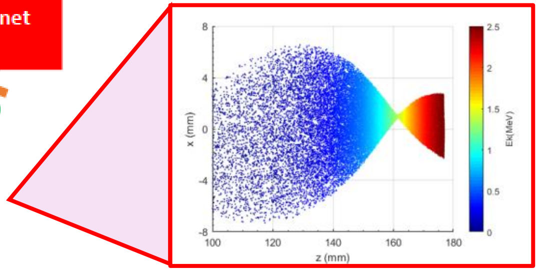


Objectives

- To Systematic errors of emittance measurement
- To evaluate the normalized emittance
- To development of the experimental setup to analyze normalized emittance

Introduction

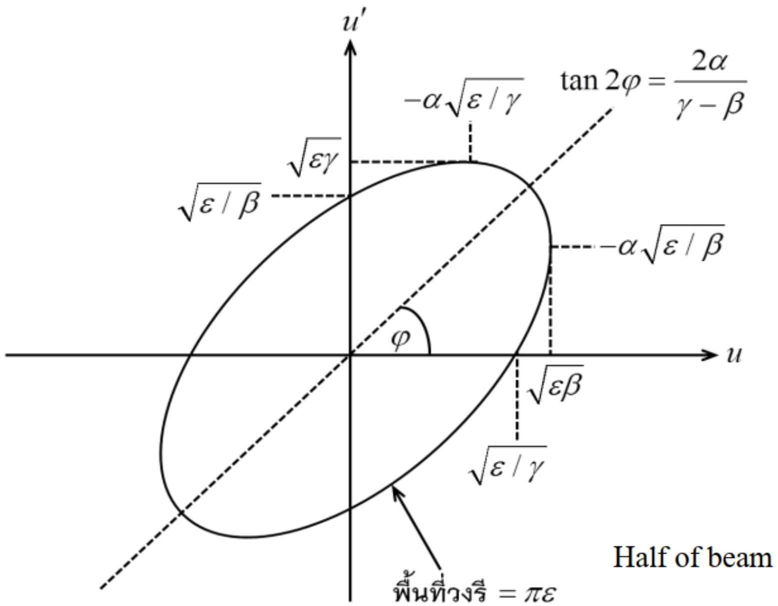


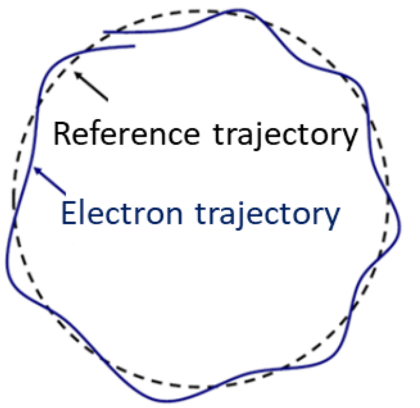


Properties	Value
Electron beam energy (MeV)	16
Bunch charge (pC)	50
RMS bunch length (fs)	203.4
Peak current (A)	245.7
Horizontal emittance (mm·mrad)	0.34
Vertical emittance (mm·mrad)	0.35
Frequency of THz radiation (THz)	3

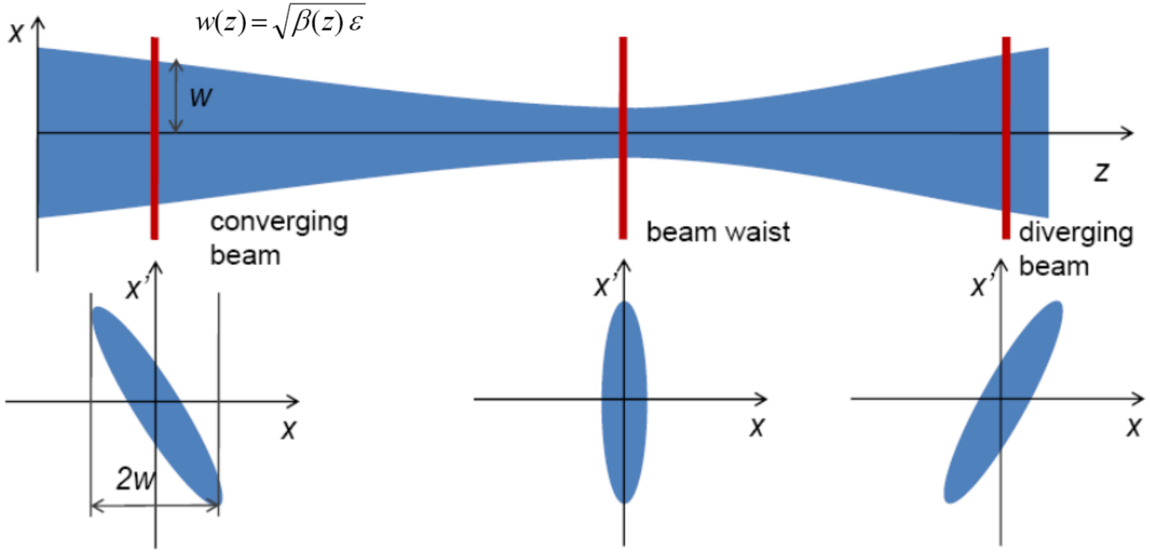
Natthawut Chaisueb, *Computer Simulated Optimization of THz Free-electron Laser Light Sources Using Thermionic-cathode and Photocathode RF Electron Guns (2022)*

Emittance





Beam transverse side



Beam longitudinal side

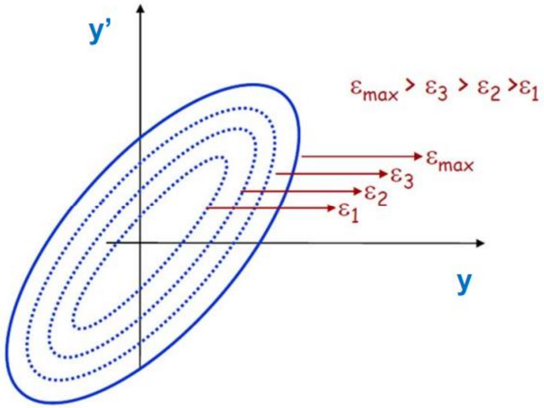
Half of beam width [m] $= \sqrt{\varepsilon\beta}$

Beam divergence [rad] $= \sqrt{\varepsilon\gamma}$

Vertical intersect [rad] $= \sqrt{\frac{\varepsilon}{\beta}}$

Horizontal intersect [m] $= \sqrt{\frac{\varepsilon}{\gamma}}$

Particle Beam Matrix : $\sigma = \begin{bmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{21} & \sigma_{22} \end{bmatrix} = \varepsilon \begin{bmatrix} \beta & -\alpha \\ -\alpha & \gamma \end{bmatrix}$

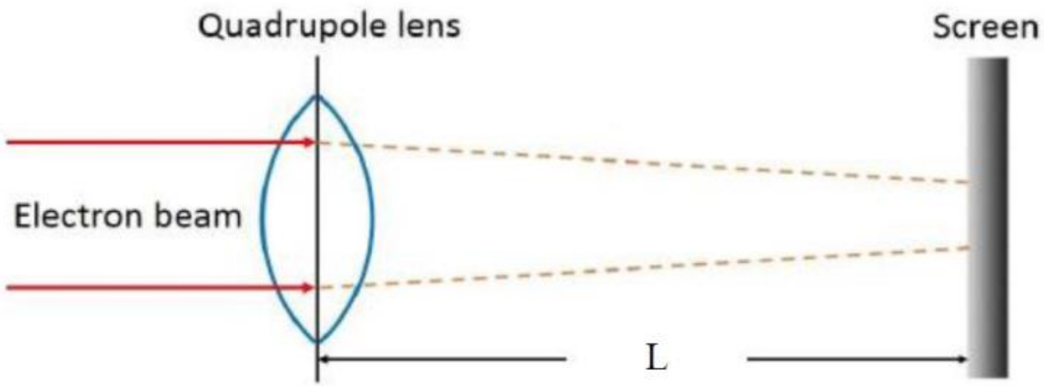


Emittance : $\boxed{\varepsilon = \sqrt{\det \sigma} = \sqrt{\sigma_{11}\sigma_{22} - \sigma_{12}^2}}$

$\sigma \equiv$ beam size matrix
$\alpha, \beta, \gamma, \equiv$ Twiss parameters

Normalize Emittance : $\boxed{\varepsilon_n = \gamma\beta\varepsilon}$ $\quad \gamma = \frac{E}{mc^2}$

Single Quadrupole Scan



$$k[m^{-2}] = 0.2998\frac{Zg[T/m]}{p[GeV/c]} = 0.2998\frac{Zg[T/m]}{\beta E[GeV]}$$

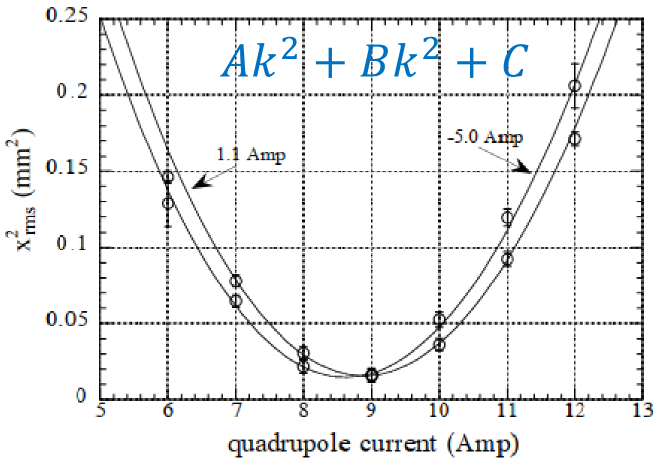
Transformation matrix of **Quadrupole => Screen**

$$X_s = RX_q \Rightarrow \sigma_s = R\sigma_q R^T$$

$$\boxed{\sigma_{s11} = R_{11}^2\sigma_{q11} + 2R_{11}R_{12}\sigma_{q12} + R_{22}^2\sigma_{q22}}$$

$$R = \begin{bmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{bmatrix} = \begin{bmatrix} 1 & L \\ 0 & 1 \end{bmatrix}\begin{bmatrix} 1 & 0 \\ -1/f & 1 \end{bmatrix}$$

Instead of the value R： $\sigma_{s11} = L^2(\sigma_q)_{11}\frac{1}{f^2} - 2L[(\sigma_q)_{11} + L(\sigma_q)_{12}]\frac{1}{f} + [(\sigma_q)_{11} + 2L(\sigma_q)_{12} + L^2(\sigma_q)_{22}]$



$$f = \frac{1}{kl_{eff}};\ \sigma_{s11} = L^2\sigma_{q11}l^2k^2 - 2L(\sigma_{q11} + L\sigma_{q12})kl + (\sigma_{q11} + 2L\sigma_{q12} + L^2\sigma_{22}) - -(1)$$

$$\sigma_{s11} = Ak^2 + Bk + C - -(2)$$

Equation (1), (2);

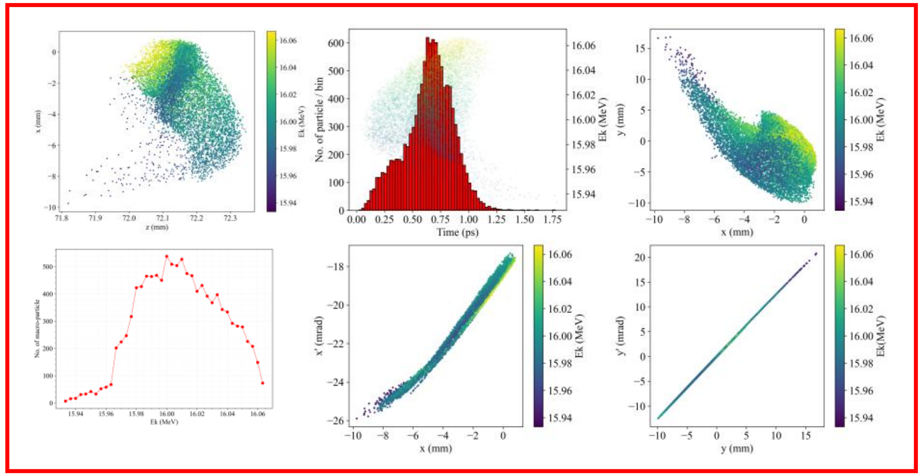
$$\left.\begin{aligned} A &= L^2\sigma_{q11}l^2 \\ B &= -2Ll(\sigma_{q11} + L\sigma_{q12}) \\ C &= \sigma_{q11} + 2L\sigma_{q12} + L^2\sigma_{22} \end{aligned}\right\}$$

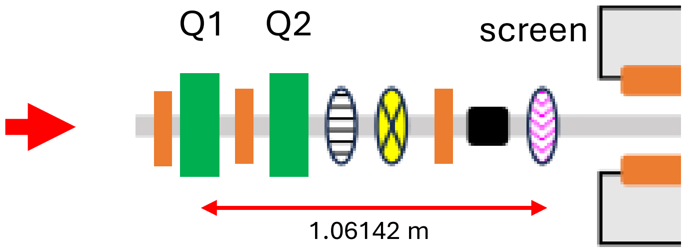
$$\boxed{\varepsilon = \sqrt{\sigma_{11}\sigma_{22} - \sigma_{12}^2}}$$

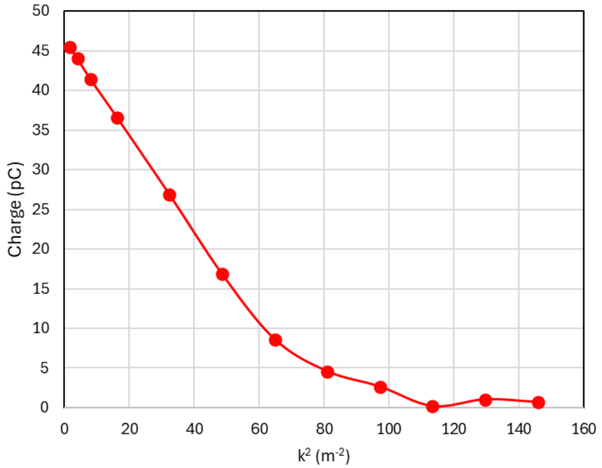
Single Quadrupole Scan

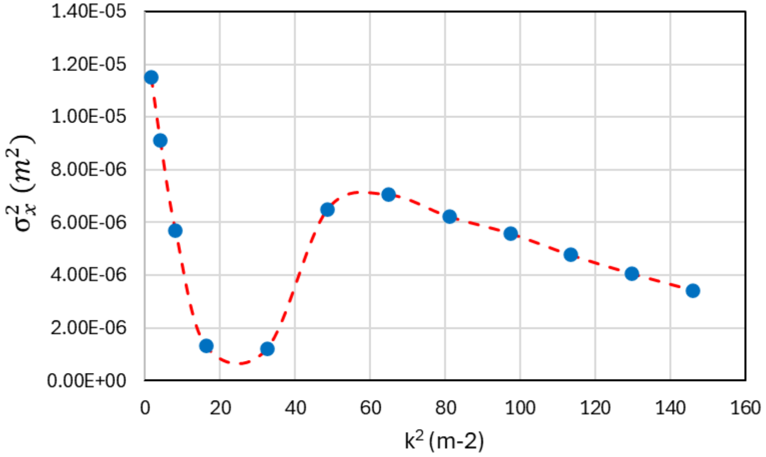
Electron beam input

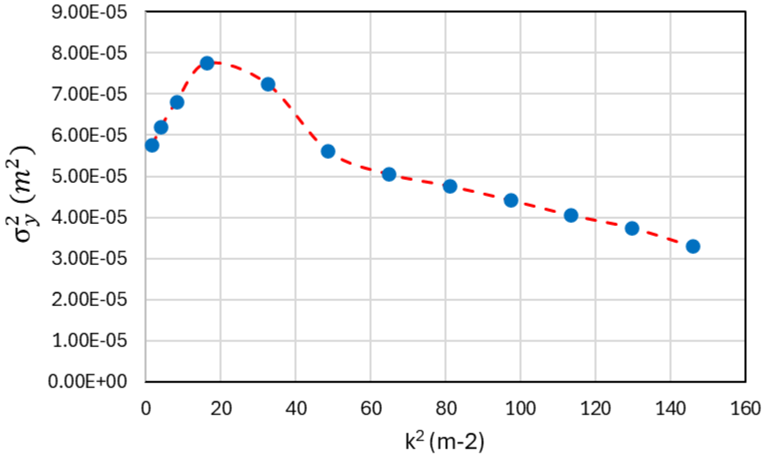
parameter	value
X_{rms} (mm)	1.9524
Y_{rms} (mm)	3.8256
ε_x $(mm.mrad)$	36.1314
ε_y $(mm.mrad)$	0.2402
Ek mean (keV)	26.1908
Bunch charge (pC)	51.177
Bunch length (ps)	0.2165



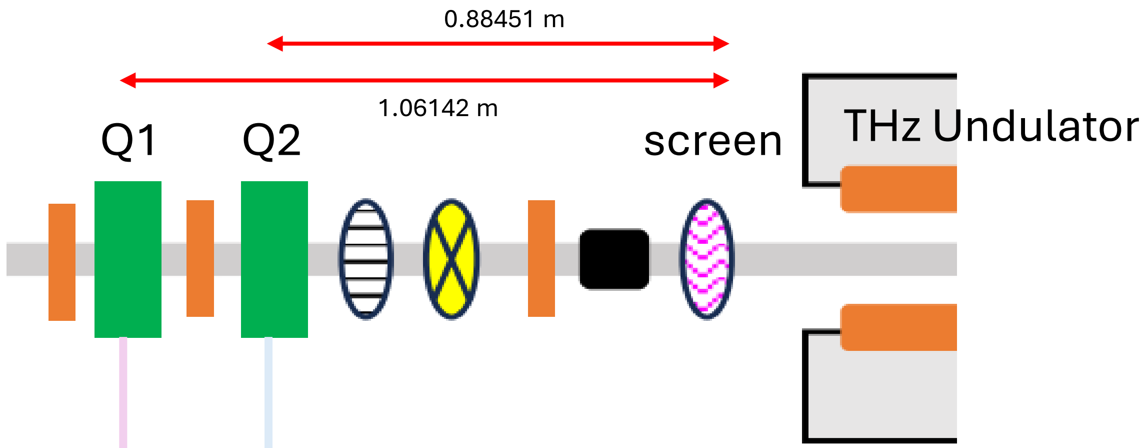








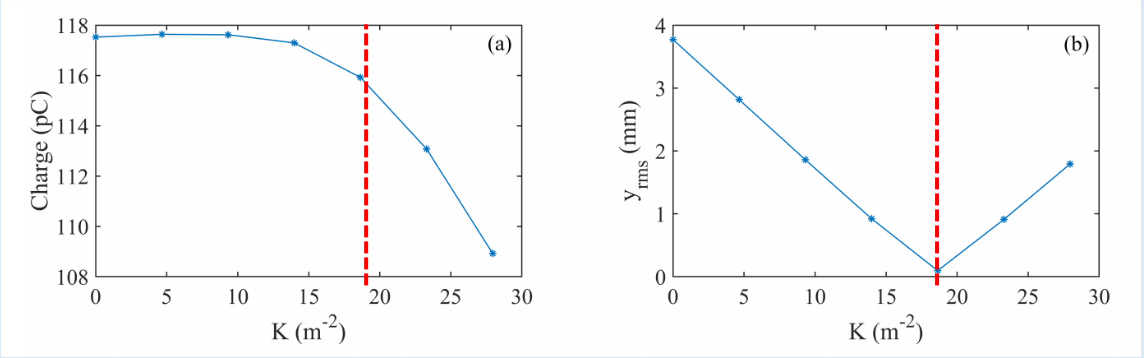
Double Quadrupole Scan



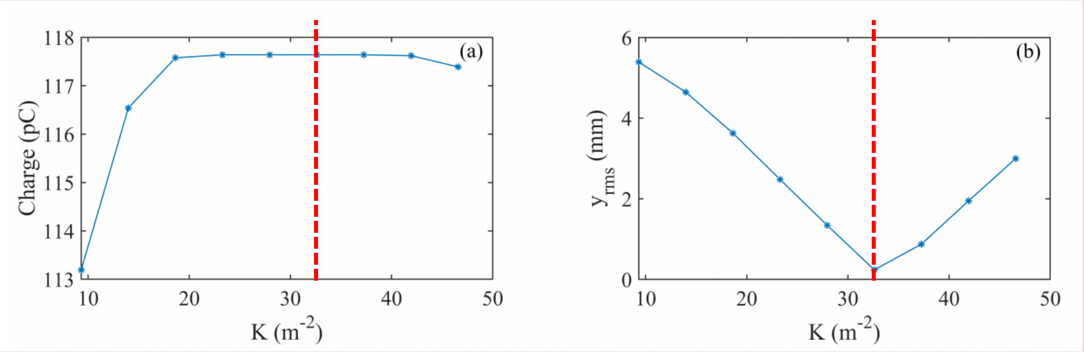
Used to scan the electron beam size

Used to control the beam size to minimize lose of charged particles before reaching the screen

Lose charged particles



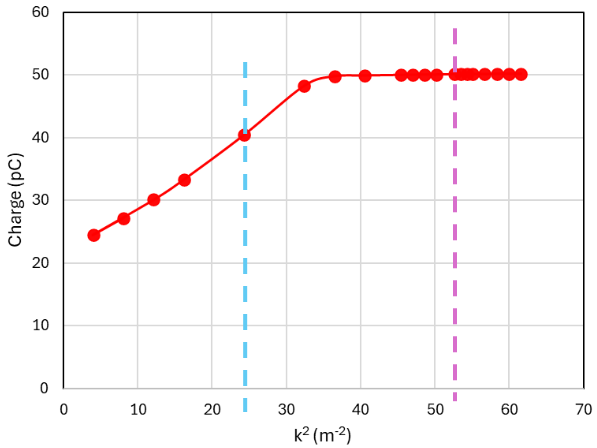
No loss of charged particles

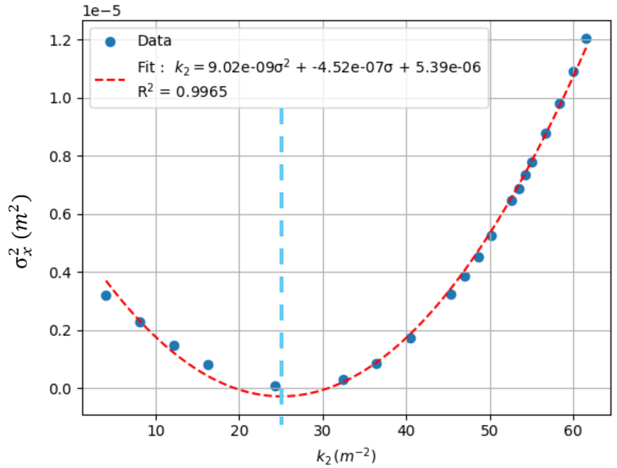


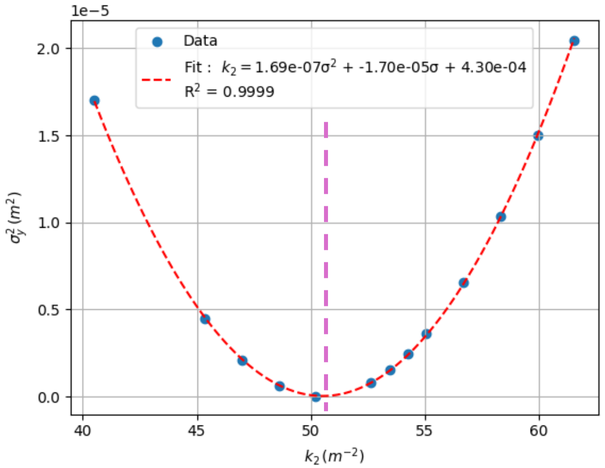
Kittipong Techakaew, *Simulation and Characterization of Electron Beams Produced from the PBP-CMU Electron LinearAccelerator Injector System (2020)*

Double Quadrupole Scan

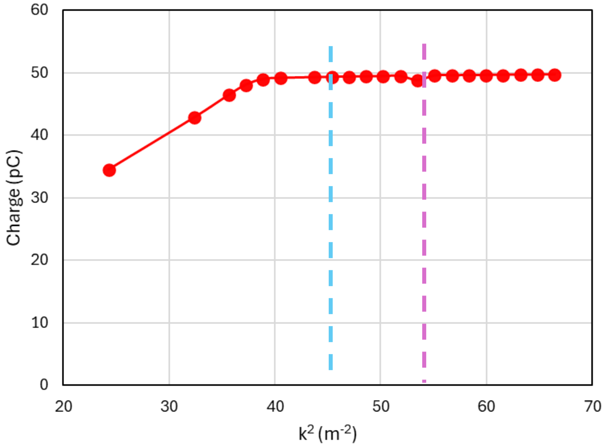
$k_1 = 1.56\ m^{-2}$

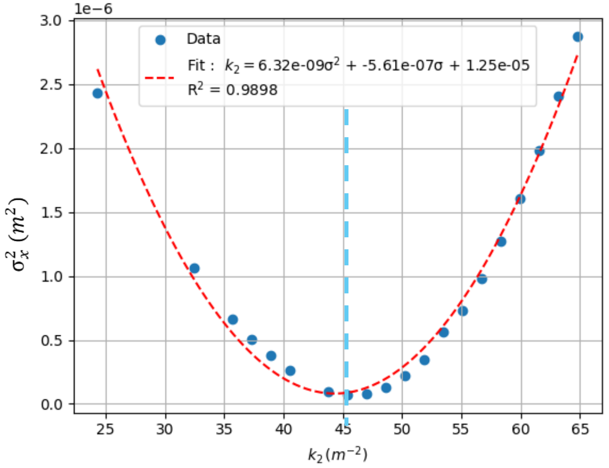


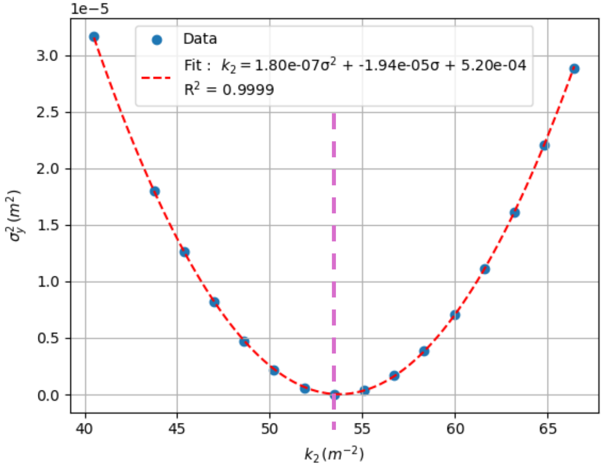




$k_1 = 1.87\ m^{-2}$

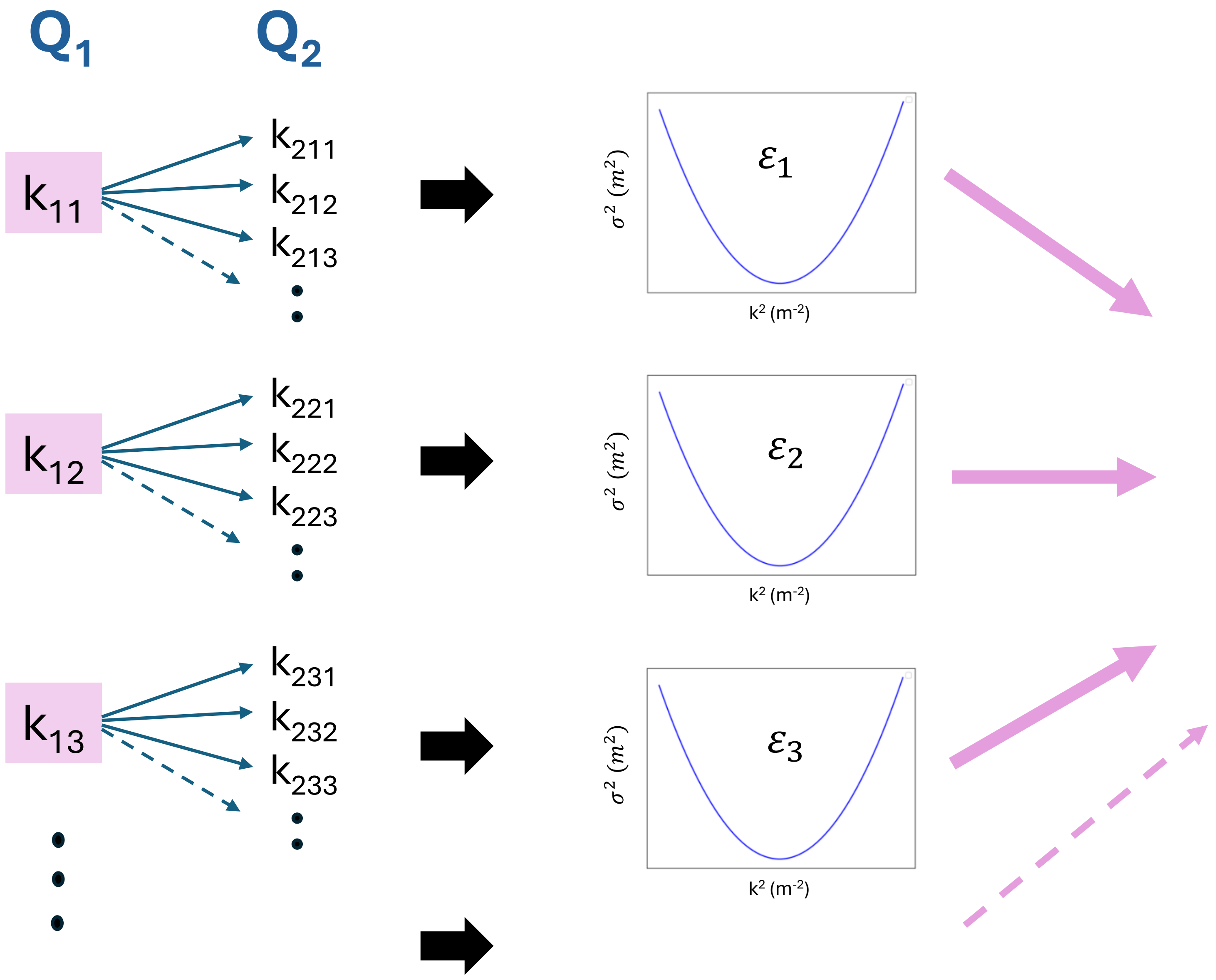


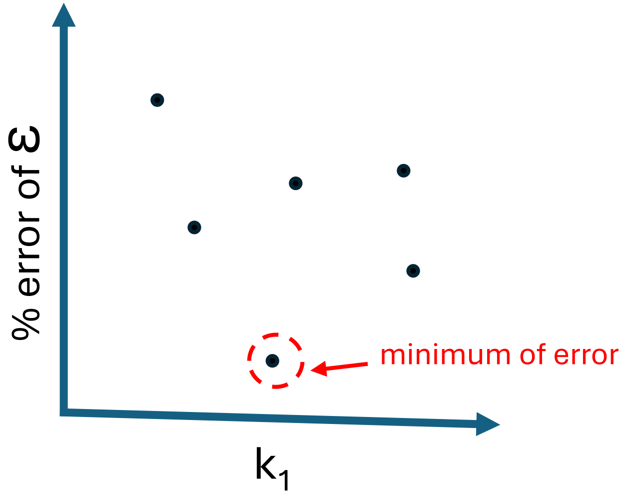




Next step

Double Quadrupole Scan





- Systematic errors of emittance measurement
- Quadrupole strange (k_1)
- Normalize Emittance

Thank you for attention