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Beam Optics Optimization in the KEK Digital Accelerator LEBT Considering the Effect of Remnant Magnetic Fields

(KEK-DA LEBT残留磁場影響におけるイオンビームオプティックス最適化)

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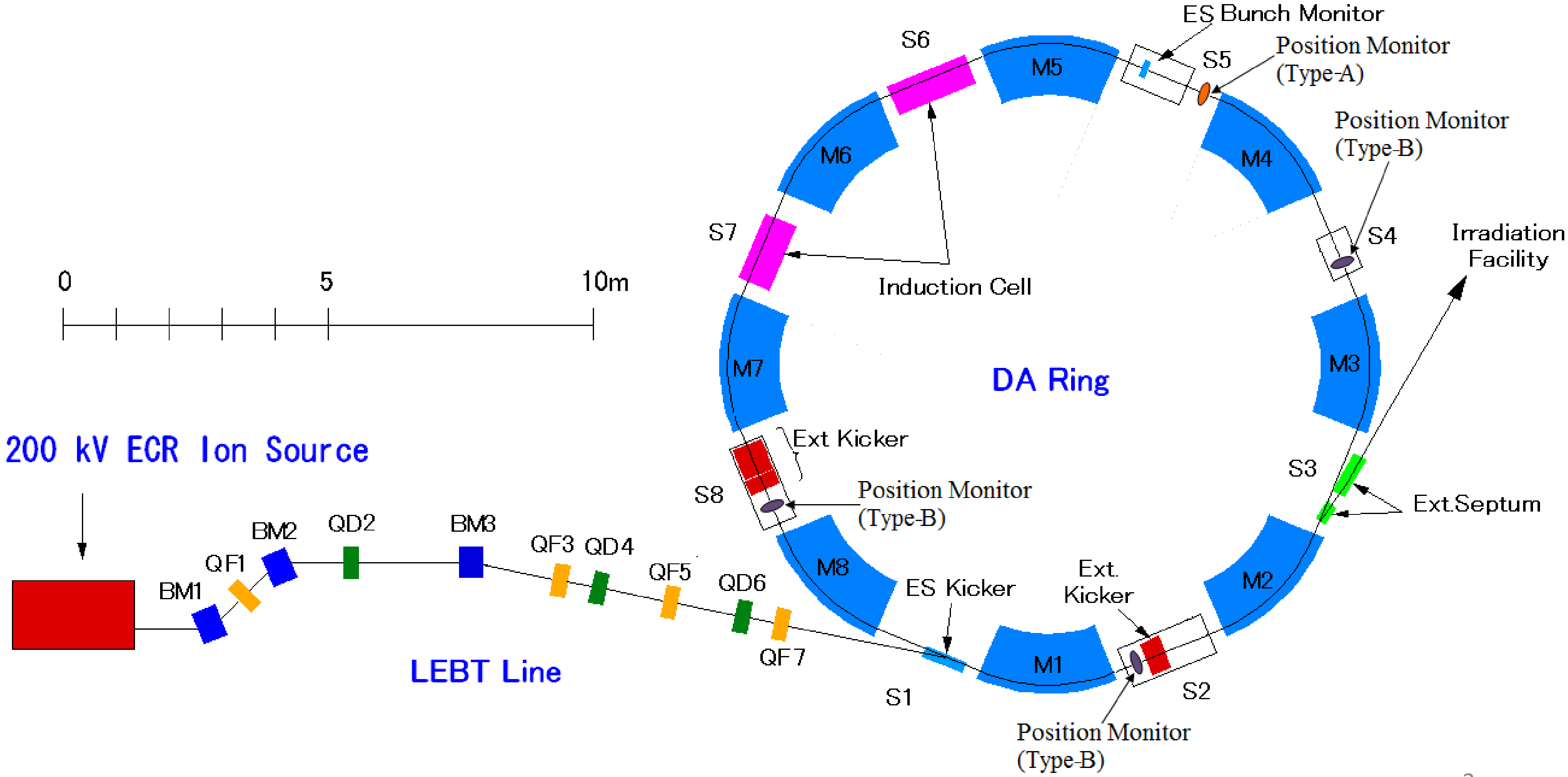
SYLLABUS

- About KEK Digital Accelerator
- Motivation
- Theoretical Background
- Experimental Set-up and Observation
- Data Analysis Results
- Discussion
- Summary and Future work

About KEK Digital Accelerator

[1] K.Takayama, and J.Kishiro, *Nucl. Inst. Meth. Phys. Res. A* 451, 304 (2000).
[2] T. Iwashita et al., *Phys. Rev. ST-AB* **14**, 071301 (2011).



Motivation

	Diagnostics	Correction
1 Steering error* Off-center/tilted	Betatron oscillation in the ring with BPMs	Steering magnets before injection
2 Optics mismatch	Twiss parameters at injection with beam profile monitors	Focusing strength of (Quadruple) magnets

? Mismatch at injection

↓

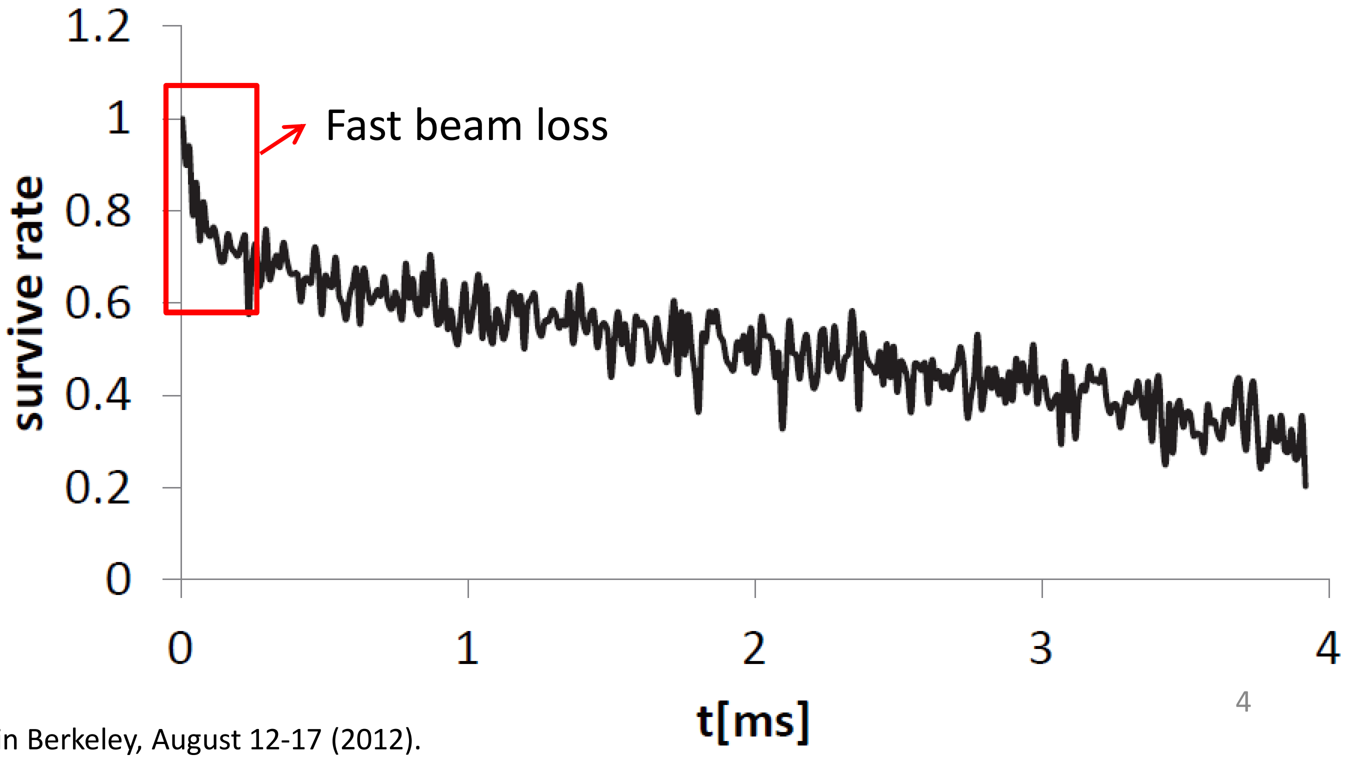
Beam emittance blow up

↓

Beam size increasing

↓

Beam loss



*T.Yoshimoto et al., in Proc. of HIF2013 in Berkeley, August 12-17 (2012).

Theoretical Background

the magnetic settings
(excitation currents)

↓

m_{11}, m_{12}, m_{13}

↓

$\varepsilon\beta_1$

$$[\varepsilon\beta_1]^i = m_{11}^i \varepsilon\beta_0 + m_{12}^i \varepsilon\alpha_0 + m_{13}^i \varepsilon\gamma_0$$
$$i = 1, 2, 3, 4, 5, \cdots, n$$

$\epsilon - emittance$

$$\varepsilon\beta_1 = m_{11}\varepsilon\beta_0 + m_{12}\varepsilon\alpha_0 + m_{13}\varepsilon\gamma_0$$

fitting for $(\varepsilon\beta_0, \varepsilon\alpha_0, \varepsilon\gamma_0)$

$$\varepsilon = \sqrt{\varepsilon\beta_0 \varepsilon\gamma_0 - \varepsilon\alpha_0}$$

and

$\beta_0, \alpha_0, \gamma_0$

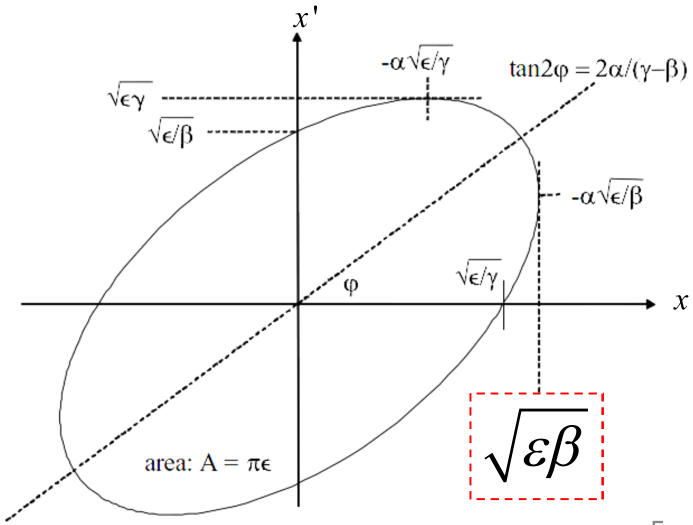
with specific setting
tranfer these for $(\beta_1, \alpha_1, \gamma_1)$

Compare with ring lattice
for mismatch estimation

from s_0 to s_1,

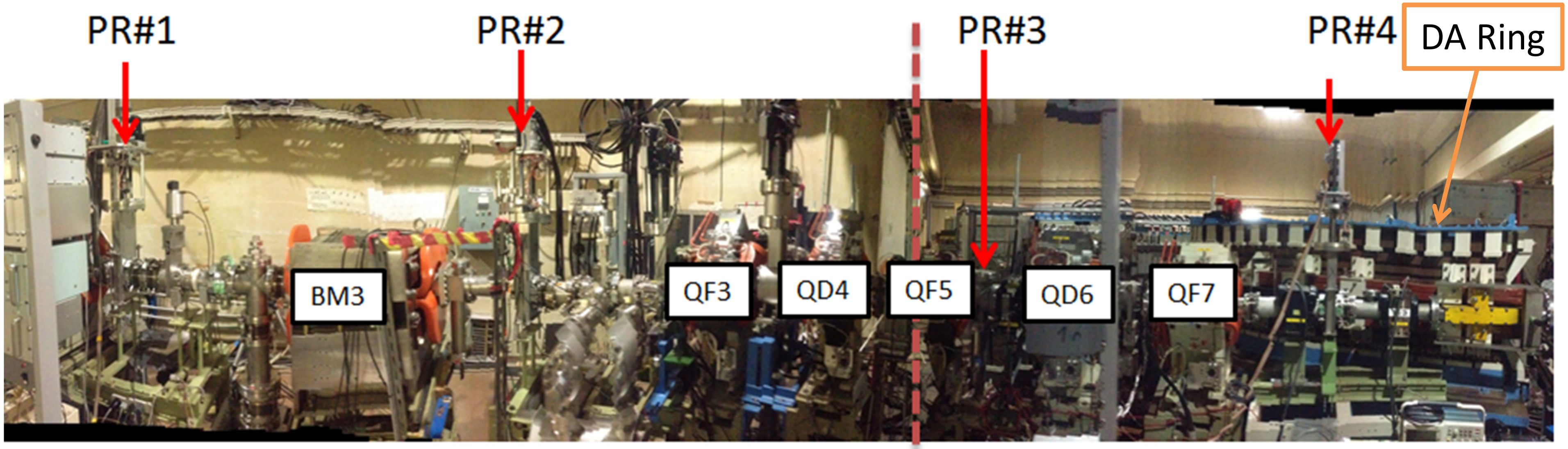
$$\begin{pmatrix} \beta_1 \\ \alpha_1 \\ \gamma_1 \end{pmatrix} = \begin{pmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{pmatrix} \begin{pmatrix} \beta_0 \\ \alpha_0 \\ \gamma_0 \end{pmatrix}$$

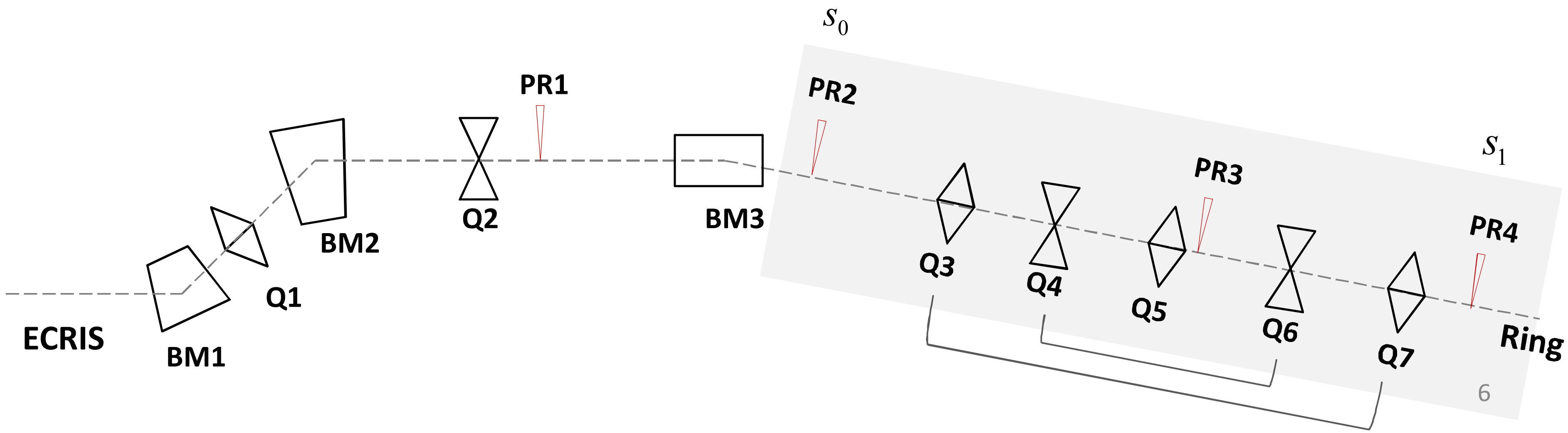
$$\begin{pmatrix} \varepsilon\beta_1 \\ \varepsilon\alpha_1 \\ \varepsilon\gamma_1 \end{pmatrix} = \begin{pmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{pmatrix} \begin{pmatrix} \varepsilon\beta_0 \\ \varepsilon\alpha_0 \\ \varepsilon\gamma_0 \end{pmatrix}$$



H. Wiedemann, *Particle Accelerator Physics (3rd Ed.)*, p158

LEBT and Wire Monitors





Quadruples and their remnant parts

Focusing Plane

$$\begin{pmatrix} \mathrm{Cos}[l\sqrt{k}] & \frac{1}{\sqrt{k}}\mathrm{Sin}[l\sqrt{k}] \\ -\sqrt{k}\mathrm{Sin}[l\sqrt{k}] & \mathrm{Cos}[l\sqrt{k}] \end{pmatrix}$$

$$k = \frac{B'}{B\rho}$$

$B\rho$ → Magnetic rigidity

Defocusing Plane

$$\begin{pmatrix} \mathrm{Cosh}[l\sqrt{k}] & \frac{1}{\sqrt{k}}\mathrm{Sinh}[l\sqrt{k}] \\ \sqrt{k}\mathrm{Sinh}[l\sqrt{k}] & \mathrm{Cosh}[l\sqrt{k}] \end{pmatrix}$$

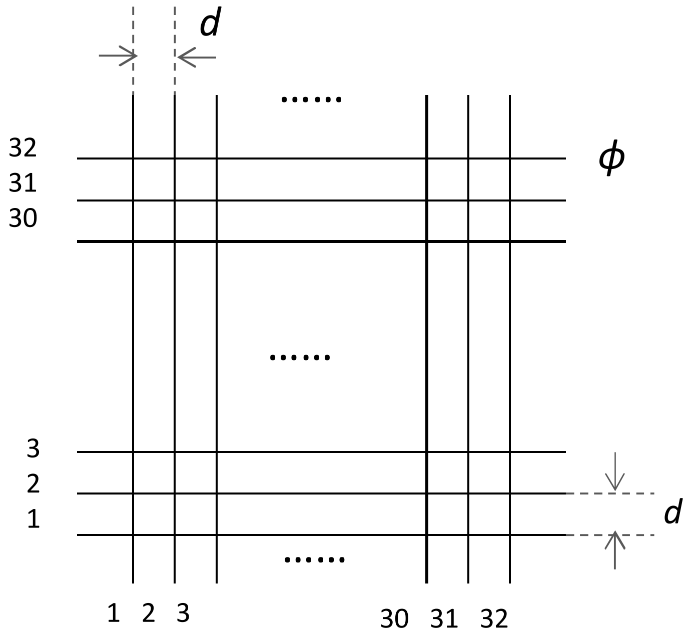
$$\mathrm{B}' = \mathrm{g} \times I[A] + b$$

b → Remnant part

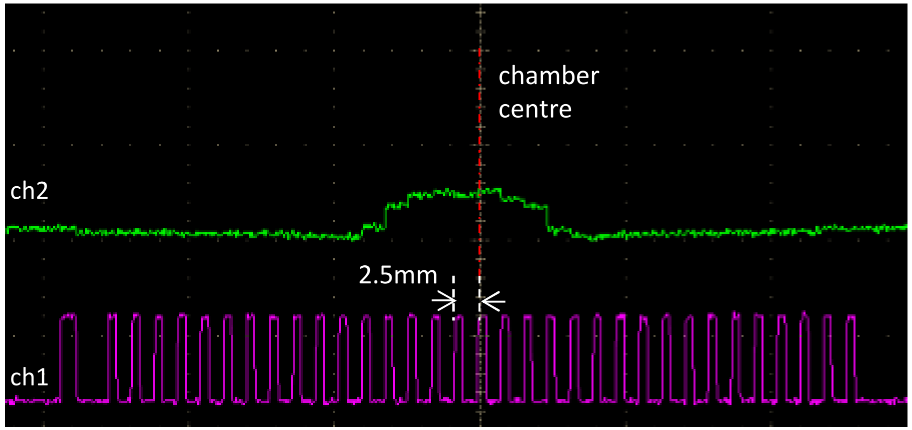
g	b
0.0408	0.0207

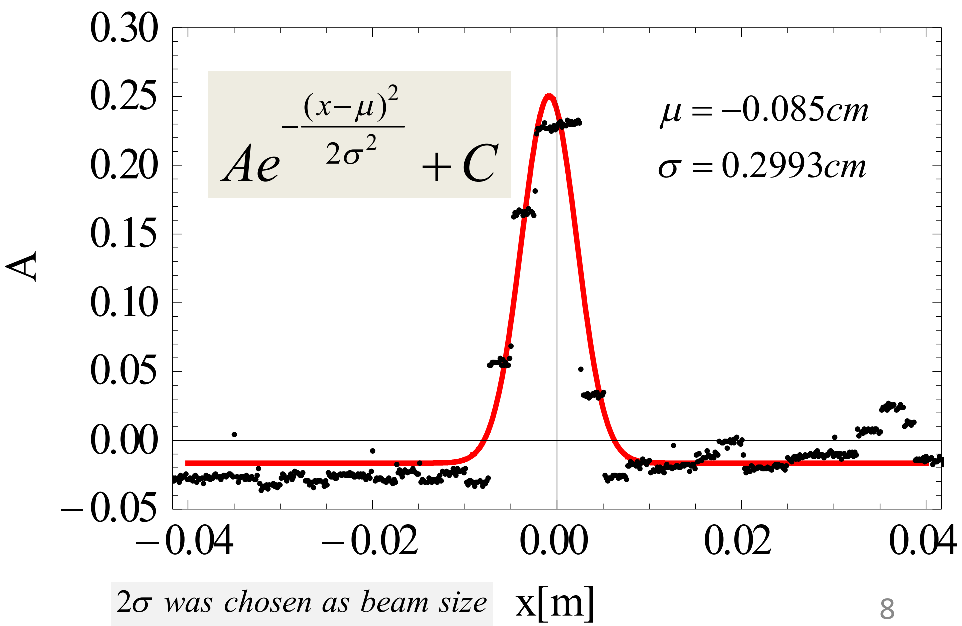
* KEK DA Note 08-92 (*internal report*).

Wire Monitor and its signal



ϕ	30 µm
d	2.5 mm
H/V	32 ch.

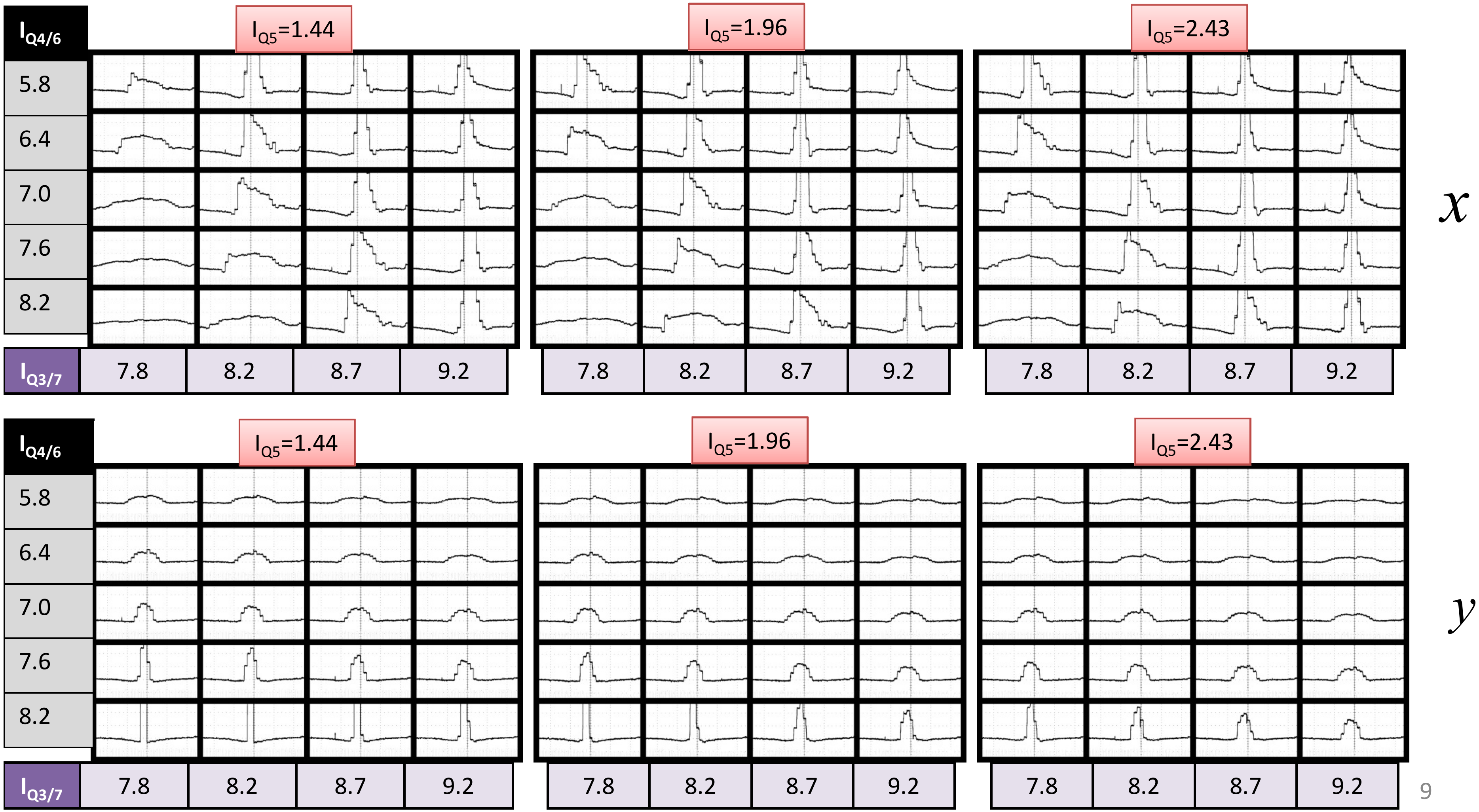




2σ was chosen as beam size in this analysis

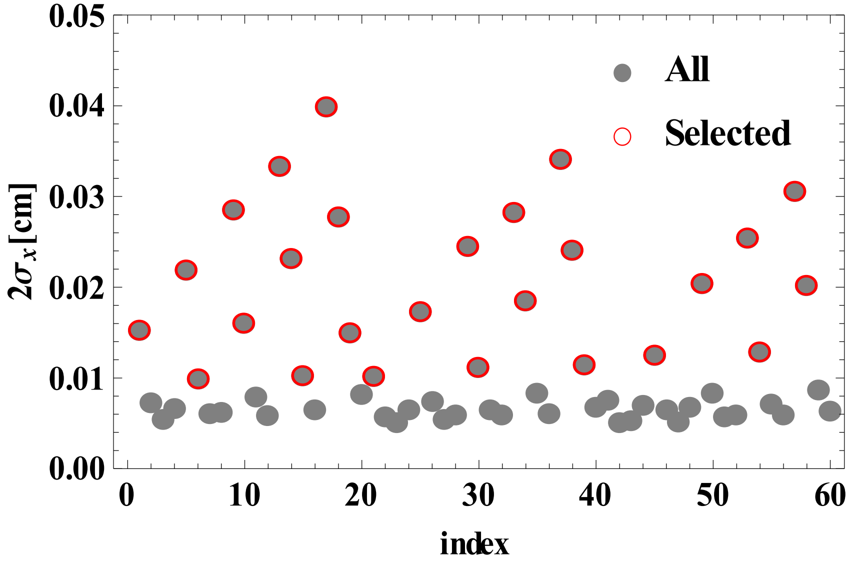
Experimental Observation(PR4)

excitation currents → m_{11}, m_{12}, m_{13} → $\varepsilon\beta_1(beam\ size)$

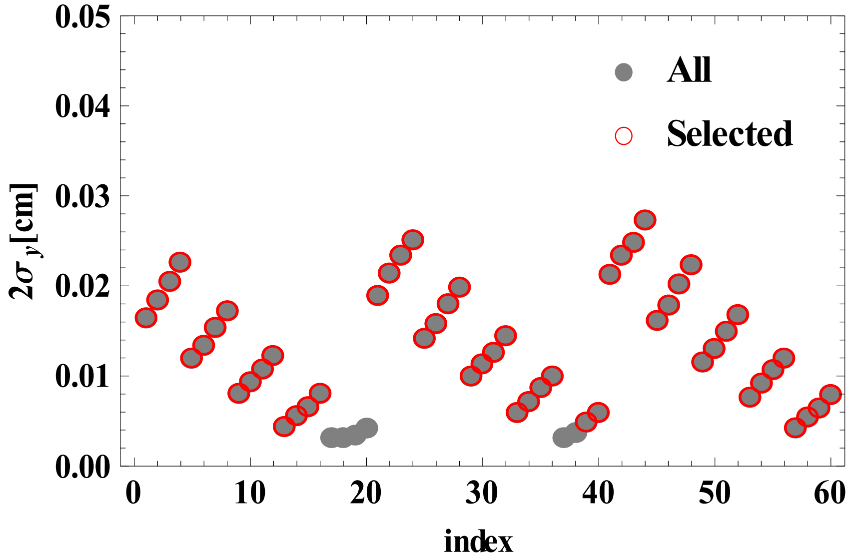


Data Selection and Constraints

Beam size $2\sigma_x$ at PR4



Beam size $2\sigma_y$ at PR4



Constraints

Beam size at PR2:

$$2\sigma_x = \sqrt{\varepsilon_x \beta_{x0}} = 1.2cm$$

$$2\sigma_y = \sqrt{\varepsilon_y \beta_{y0}} = 0.6cm$$

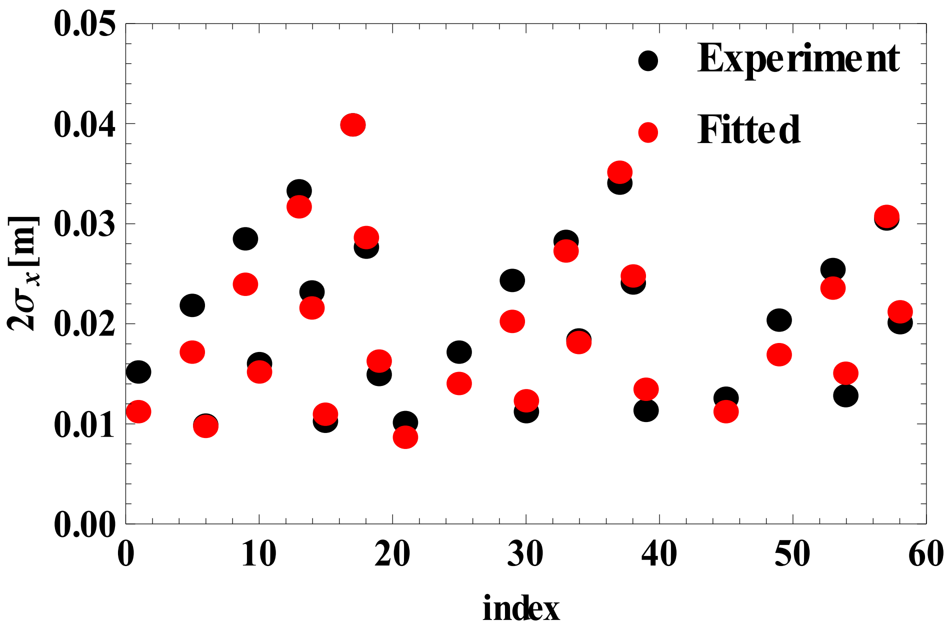
Beam emittance

$$\varepsilon = \sqrt{\varepsilon\beta_0 \varepsilon\gamma_0 - \varepsilon\alpha_0} > 0$$

Fitting Results

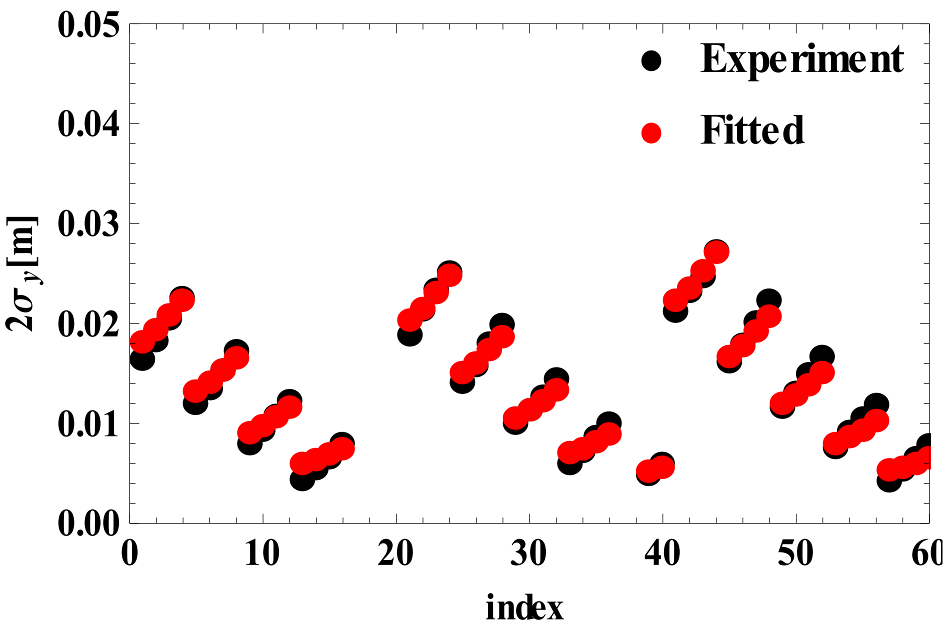
With remnant part all be 0.0207

Horizontal



β_{x0}[m]	α_{x0}	γ_{x0}	$\varepsilon_x[\mu m \cdot rad]$	$2\sigma_{x0}$
3.32	-3.51	4.02	44.98	1.22

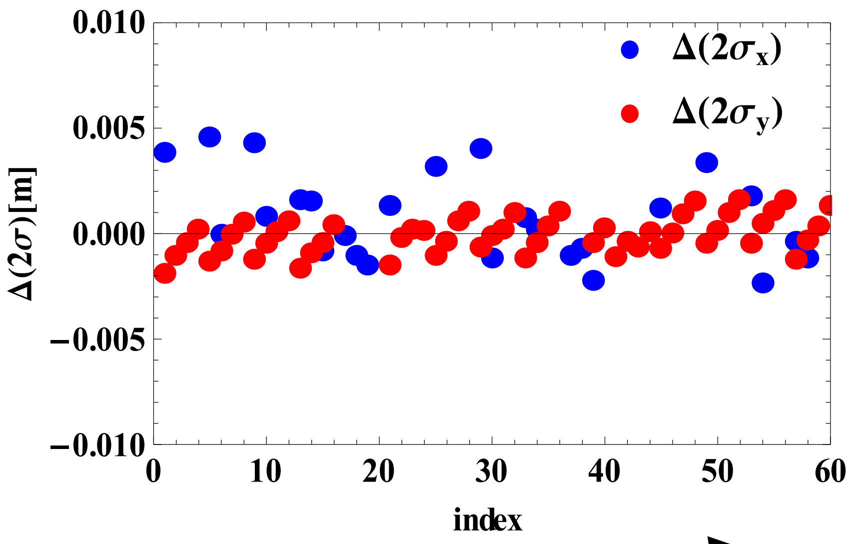
Vertical



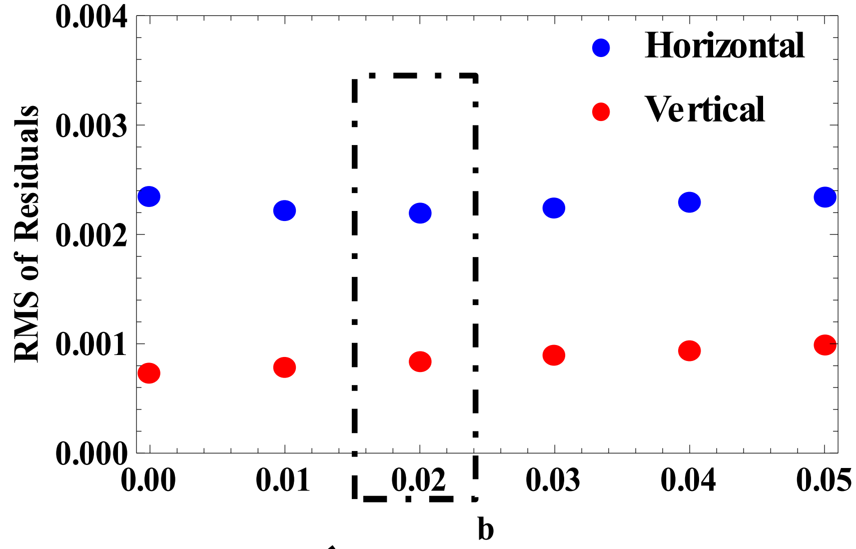
β_{y0}[m]	α_{y0}	γ_{y0}	$\varepsilon_y[\mu m \cdot rad]$	$2\sigma_{y0}$
2.48	1.44	.24	24.78	0.78

Remnant Part

Fitting Residuals



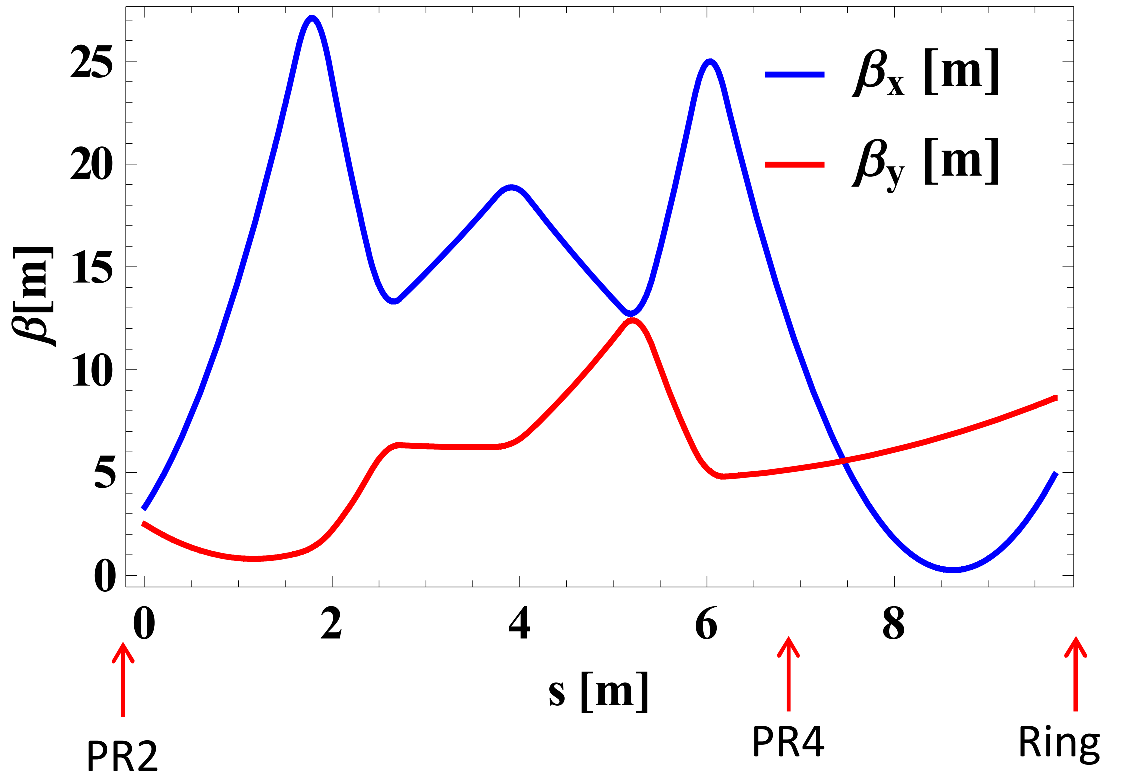
RMS of Residuals



$$B' = g \cdot I[A] + \mathbf{b}$$

#1 The residuals follow the same pattern as data points
#2 With all remnant parts the same, present choice is a good one

Beta Function



	Excitation Current(A)
$I_{Q3/Q7}$	**7.5**
$I_{Q4/Q6}$	**7.0**
I_{Q5}	**2.3**

	Beam size(cm)
x_{max}	**3.5**
y_{max}	**1.8**
x_{min}	**0.7**
y_{min}	**0.5**

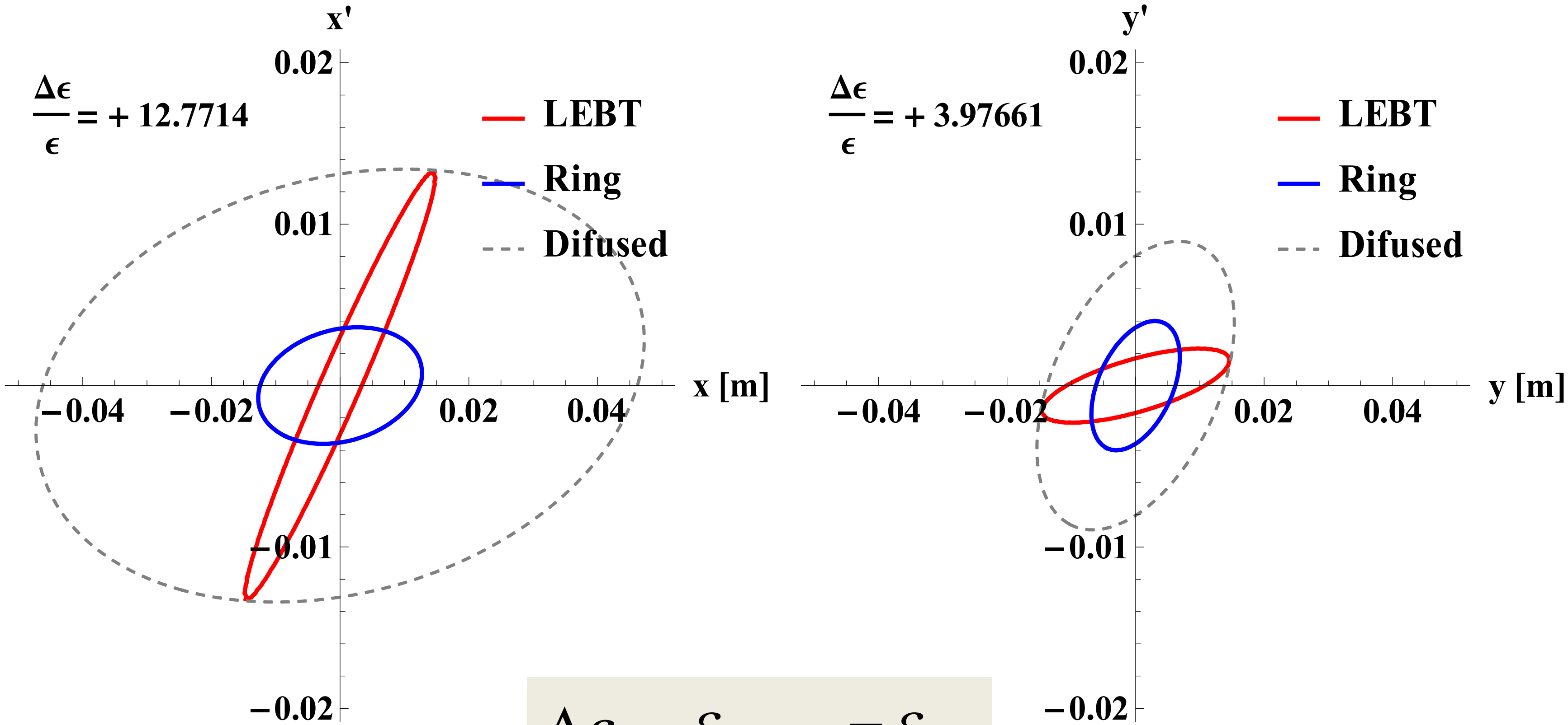
LEBT Lattice

β_{xi}	α_{xi}	γ_{xi}
4.89	-4.26	3.92
β_{yi}	α_{yi}	γ_{yi}
8.62	-0.92	0.21

Ring Lattice

β_{xr}	α_{xr}	γ_{xr}
3.60	-0.22	0.29
β_{yr}	α_{yr}	γ_{yr}
1.90	0.48	0.65

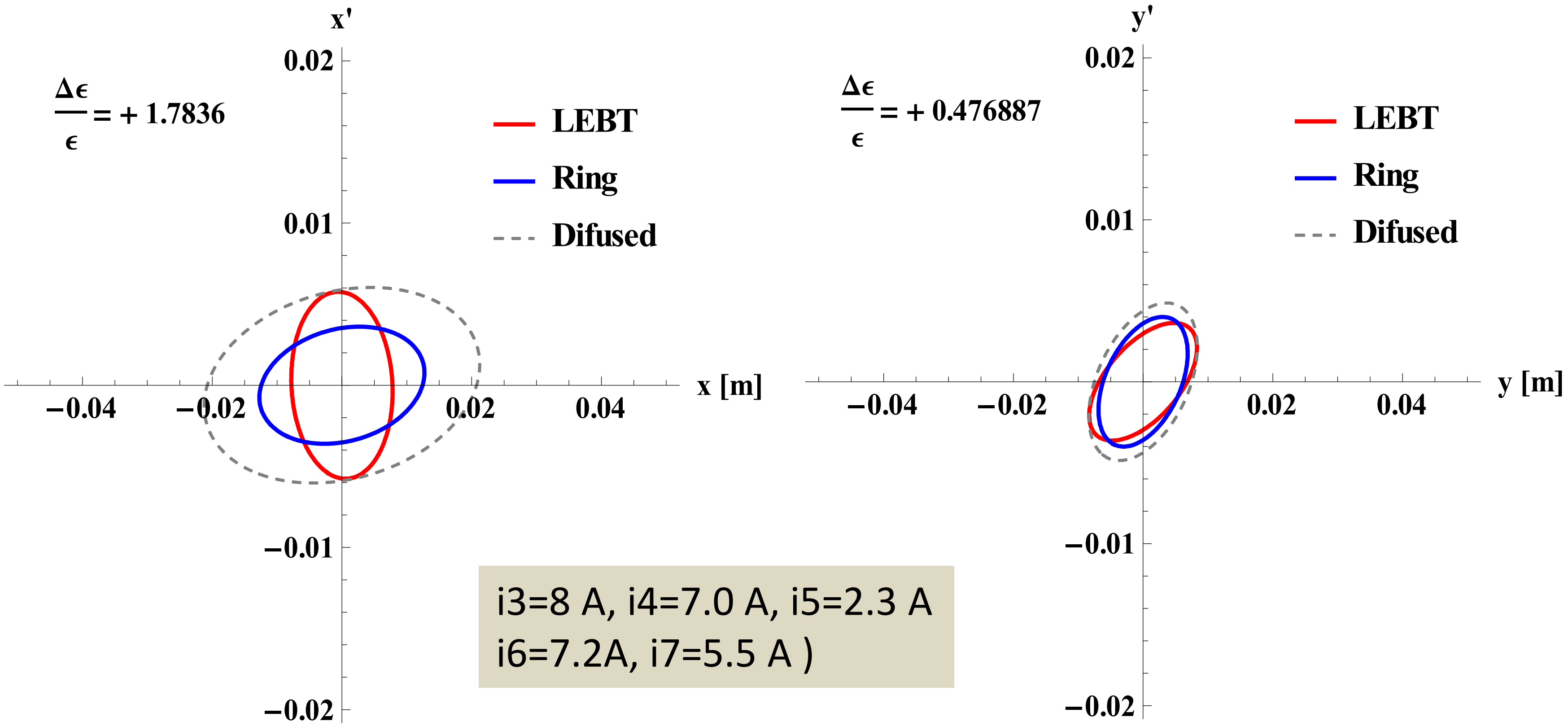
Injection Mismatch



$$\frac{\Delta \varepsilon}{\varepsilon} = \frac{\varepsilon_{difused} - \varepsilon_{inj}}{\varepsilon_{inj}}$$

Possible Solutions

#1 Independent excitation currents



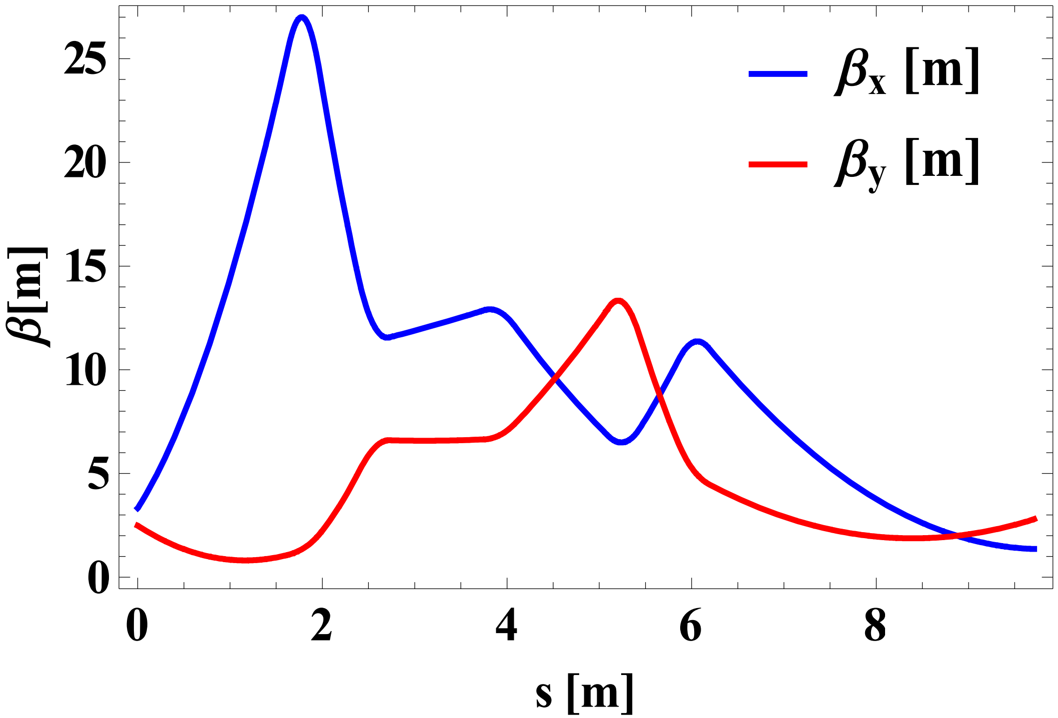
i3=8 A, i4=7.0 A, i5=2.3 A
i6=7.2A, i7=5.5 A)

#2 Upstream optimization

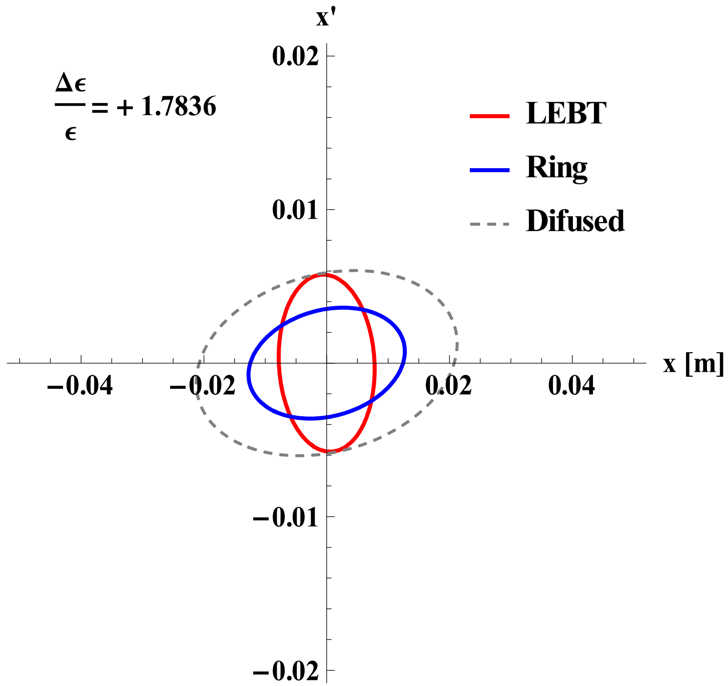
Summary and Future Works

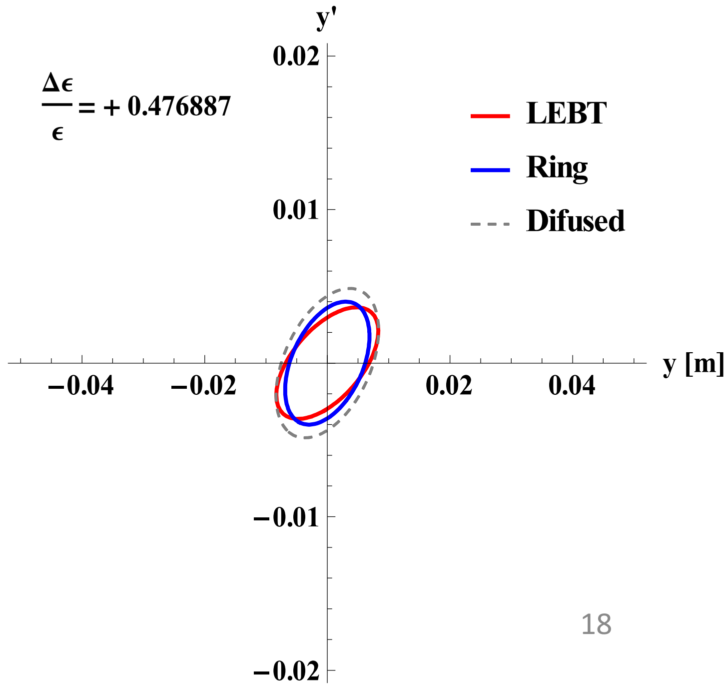
- ✓ With the help of wire monitors, the Twiss parameters and emittance in LEBT region could be determined experimentally
- ✓ Consequently, the optics focusing mismatch could be estimated
- ✓ Experiments aiming at the two possible solutions are planned after summer shutdown and hopefully we can reduce the fast beam loss at the beginning of commissioning

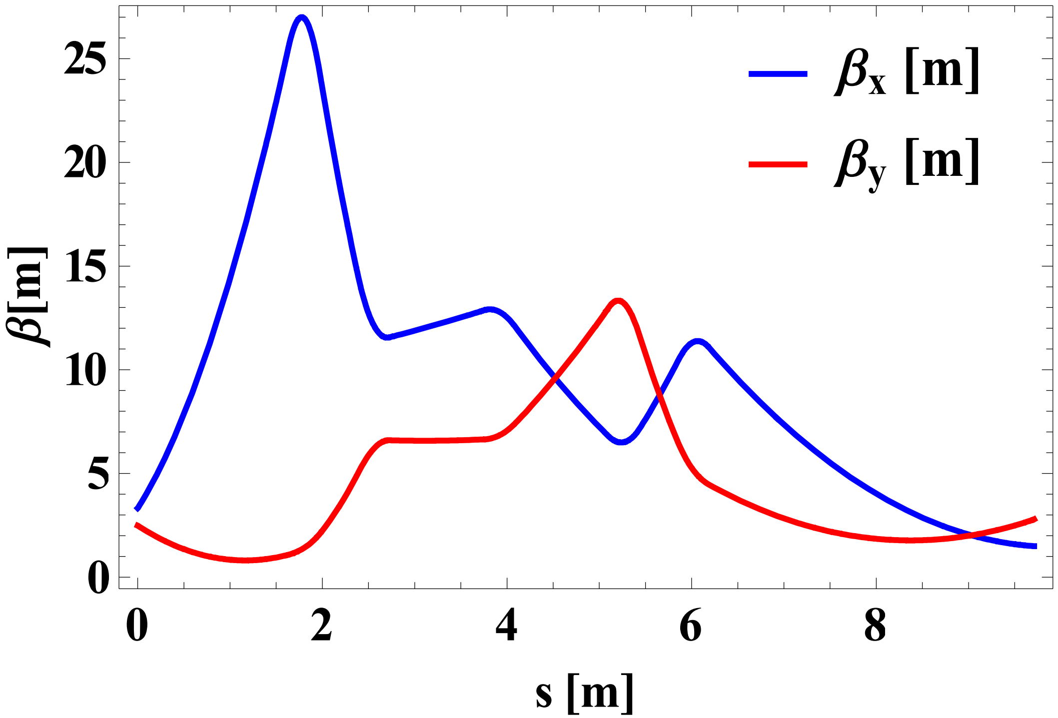
THANKS



{iQ3, iQ4, iQ5, iQ6, iQ7}
= {8., 7,2.3,7.2,5.5}







$\{iQ3, iQ4, iQ5, iQ6, iQ7\}$

$= \{8., 7, 2.3, 7.2, 5.4\}$